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DIGITAL TELEVISION ROUTING SYSTEMS:

A survey of optical and electrical techniques

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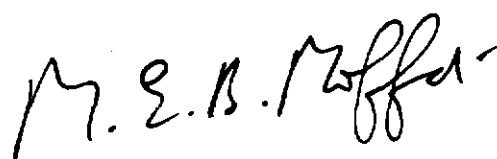
**DIGITAL TELEVISION ROUTING SYSTEMS:
A SURVEY OF OPTICAL AND ELECTRICAL TECHNIQUES**

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Summary

The requirements for a digital video routing system for a studio centre are reviewed. A large routing system capable of interconnecting more than 100 sources and 100 destinations is required. The options are described and compared. The high bit rate of digital video is well suited to optical fibre systems, but there are no suitable optical switches. Consequently an optical system based on a passive star network is recommended. Time-division and optical wavelength-division multiplexing is used to achieve the required capacity. The system would be based on components now being developed for telecommunications networks. So strong are the advantages of the recommended system that even if optical switching were to become practical the passive star network would probably still be preferred.

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1. INTRODUCTION

The Central Apparatus Room (CAR) at the BBC's London Television Centre is due to be refurbished in the 1990s. This room contains the main switching matrices through which the video, audio and ancillary signals are routed between studios, technical areas and outside operations, Fig. 1. The video matrix was installed in 1972 and uses field-effect transistor switches. The audio and ancillary signals are switched on uniselectors installed in 1960. Modifications and additions have been made, but the basic organisation and control of the matrix have remained unchanged. The new installation is also expected to see service for a considerable length of time, and it is therefore necessary to ask if the existing arrangement is still appropriate in the light of technical innovations.

An increasing proportion of television processing equipment is now digitally based, the best known examples being special-effects and graphics equipment. A digital routing system would avoid both the expense and impairment caused by repeated conversion of video signals between analogue and digital forms.

This Report examines the requirements for a new routing system, and reviews optical and electrical techniques for transmission and routing. Systems suitable for routing large numbers of digital video signals are then discussed. Account is taken of whether such systems could in fact be developed in time for the new installation, and whether they could be easily extended in the future. The ability of the new installation to take high-definition pictures is also considered.

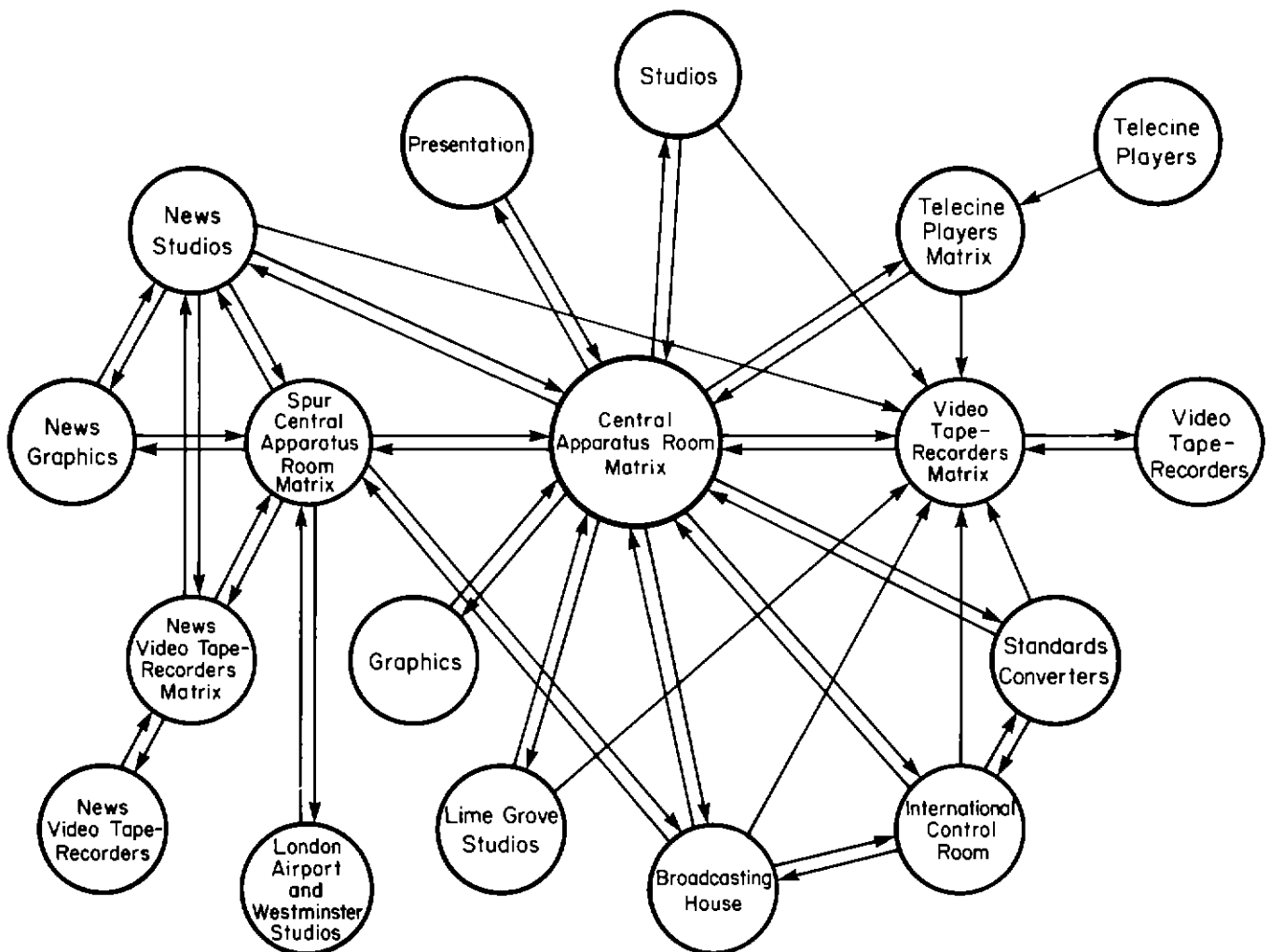


Fig. 1 - Present routing system at Television Centre.

2. REFURBISHMENT OF THE CENTRAL APPARATUS ROOM

The present routing system is basically a star network, with a large switching matrix at its centre. The matrix interconnects the individual studios with the specialised areas containing video tape-recorders, telecines and graphics equipment. It also links the Television Centre with outside-broadcast circuits, the national broadcast networks (via continuity suites), and other broadcasters (via international control rooms). Locating expensive capital equipment in specialised areas allows it to be used more intensively, by re-allocating it as demand requires. It also makes maintenance and operation easier to organise.

The size of the main matrix is 100×120 , made up from 25×12 matrices interconnected via distribution amplifiers, with a further 20 routes available via patch-panels. The matrix allows each source to be sent to several destinations at the same time, with only a few restrictions on the routes. The matrix is non-blocking; that is, existing routes do not block new routes. Solid-state switches based on field-effect transistors are used for switching the video signals. Sound and ancillary signals are switched on an associated network, using uniselectors, giving 16 levels of switching per routing.

Generally it is not necessary for the switches to be synchronised to the television waveform, or to operate within a given time, for example a bit-period of the digital data stream. The purpose of the matrix is to pre-select resources to allow programmes to be made. This is distinct from 'cuts' between programmes on transmission, or the type of switching used during editing, which do have to be synchronous.

Signals are distributed round studio centres by coaxial cables in ducts. At Television Centre these ducts are nearly full, so it would be an advantage if a new system could either use the existing cables or at least require only a small number of new ones. However it may not be possible to re-use the existing cables for digital video signals. The bandwidth of a digital signal is over 120 MHz, compared with only about 6 MHz for the corresponding analogue signal. Considerable equalisation would be needed at these high frequencies, with repeaters on some long runs. This problem could be avoided by replacing the coaxial cables with optical fibres.

The choice of transmission medium will also depend on economic and operational factors, and the ability to carry signals whose format has yet to be decided. For example, an electrical system might be cheaper than an optical or an electrical/optical hybrid, but would have to be replaced if high-definition

television (HDTV) is introduced. Most types of optical network could easily be modified to carry HDTV.

Above all, a new routing network must provide at least the same facilities as the present network:

- (1) The network must be able to deal with at least 100 sources and 100 destinations.
- (2) Any source must be available at any number of destinations simultaneously.
- (3) Setting up any one connection must not block others (except that two signals may not be sent to the same destination simultaneously).
- (4) Changing one connection must not disturb others already set up, even momentarily.

It would be desirable for a new routing system to eliminate the problems of existing systems and incorporate flexibility for the future. So the following improvements would be advantageous:

- (i) No cable equalisation or regeneration for routes up to 1 km long.
- (ii) Control from destination to be readily implemented, as an alternative to central control.
- (iii) No electrical connection between areas, eliminating problems with hum from earth loops.
- (iv) Accommodation of synchronising information, sound and ancillary signals without additional bearers and associated switching.
- (v) Easy expansion to provide extra capacity in the future.
- (vi) Accommodation of high-definition television signals.

3. THE DIGITAL VIDEO SIGNAL

An increasing proportion of television signal processing equipment now uses digital techniques. This is because it is possible to manipulate and store a digital signal to an extent not possible with analogue techniques. Examples of equipment that process the signal in digital form include time-base correctors, synchronisers, electronic 'still-picture' stores, noise reducers, test signal generators, and equipment for producing electronic graphics and special effects. A digital video tape recorder has recently become available. This can produce copies beyond the 20th generation before the errors become uncorrectable. A major benefit of digital equipment to the programme maker is the unprecedented freedom it gives to explore new techniques of programme production.

The video signal should be routed between equipment in digital form to avoid the impairments

caused by conversion between analogue and digital forms. To help ensure compatibility between digital equipment, the CCIR has issued Recommendation 601¹. This defines the signals to be digitised and the details of the sampling structure.

The digital video signal as defined by Recommendation 601 is based on components, as distinct from a composite signal. The components are a luminance signal, sampled at 13.5 MHz, and two chrominance signals, each sampled at 6.75 MHz, all quantised to 8-bit accuracy. These coding parameters were chosen to maintain picture quality through critical processes such as chroma-key.

Techniques have been developed for reducing this bit rate² for long distance transmission over telecommunications links, where a tariff saving may be made, or where the full capacity may not be available. For the short distances in a studio centre the cost and complexity of the bit-rate reduction equipment would far outweigh any advantages from the lowered transmission rate. Also, data compression techniques are not transparent and can impair the picture if used repeatedly. The studio routing system must therefore be capable of carrying the uncompressed signals.

The quest for better picture quality is expected to result in high-definition television (HDTV). No standard has been defined, although it is expected that a sampling rate with a simple relationship to Recommendation 601 will be chosen. Present proposals imply a bit rate between 1 and 2 Gbit/s.

4. A REVIEW OF ELECTRICAL TRANSMISSION TECHNIQUES

Recommendation 656 sets out the standards for transmission of digital video signals in both parallel and serial format³. It is expected that manufacturers will fit suitable interfaces to digital equipment.

4.1 Parallel electrical transmission

The parallel interface standard defined in Recommendation 656 requires the transmission of the luminance and chrominance samples alternately on eight conductor pairs at a sample rate of 27 MHz. A 27 MHz clock is carried on a ninth pair of conductors.

Although the clock rate is within the capabilities of TTL (transistor-transistor logic) circuits, the interface is implemented with ECL-compatible (emitter-coupled logic) circuits, which are better able to drive transmission lines. The Recommendation specifies 25-way sub-miniature D-type connectors and cable containing balanced-conductor pairs.

Parallel transmission is attractive because of its simplicity. Almost all digital equipment processes the signals in parallel form, so that very little extra circuitry is needed to provide the interface. Further, the bit rate is significantly lower than in the serial interface. The parallel interface is particularly attractive for small, self-contained installations, and a small experimental studio has already been demonstrated⁴.

The disadvantage of the parallel interface is that nine circuit paths are needed to convey one television picture. Cables and connectors will be larger, more expensive and inherently less reliable than for analogue transmission. Differences in signal propagation speeds along the various conductors in the cable are critical. In a large installation the concentration of signals at the switching matrix will be very difficult to deal with, and its size will be limited by the number of signals that it is possible to take on and off a circuit board via an edge-connector.

4.2 Serial electrical transmission

In the serial interface the signal is transmitted unbalanced over a single coaxial cable. There is no separate clocking signal. The 8-bit samples are first transcoded into a carefully selected set of 9-bit words, thus increasing the data rate to 243 Mbit/s. The 9-bit words are chosen so that the serialised data stream contains equal numbers of 'zeros' and 'ones'. Thus there is no DC content, and AC-coupled stages may be used in the line-receiving amplifiers. The transcoding is also designed to ensure that there are frequent transitions in the data stream for accurate clock recovery. The serial waveform is suitable for both electrical and optical transmission, although only the electrical interface is defined in the Recommendation at this stage.

Cable equalisation to compensate for high frequency loss is essential, the loss of the existing cables being approximately 120 dB/km at 120 MHz, although exact equalisation is not as critical as with analogue circuits. Large diameter coaxial cable has a better high frequency performance, about 80 dB/km loss at 120 MHz, but equalisation would still be needed and there would be less room in cable ducts. Air-spaced coaxial cable is even better, but is not robust enough for installation in operational areas.

Crosstalk from other cables carrying similar digital signals may cause errors. Crosstalk increases with frequency, and is therefore a greater problem with the serial signal than with the parallel signal. Equalisation makes the problem worse by amplifying the high frequencies. The high concentration of signals at the switching matrix is also a potential source of crosstalk.

The serial data rate is firmly in the realm of ECL circuits. Presently, parallel-to-serial conversion uses a large number of small-scale integrated circuits. The serial interface will become attractive if it can be concentrated into a few very-large-scale integrated circuits.

5. REVIEW OF FIBRE-OPTIC TRANSMISSION

Recommendation 656 leaves the standards for optical transmission to be decided. However the bit rate of the serial format described in Section 4.2, in combination with the distances involved, is well within the capacity of fibre-optic transmission. Indeed, there are several ways in which a 243 Mbit/s 1 km link could be provided. Other advantages of optical fibre are immunity to interference and small cable size. An experimental optical fibre link to carry digital television signals was built at Research Department⁵.

The major parts of a fibre-optic link are the fibre, the source, the receiver and the connectors.

There is a wide range of optical fibre available, but not all types are suitable for high-frequency signals. Telecommunications-quality optical fibre is made from silica⁶. A core of high refractive index silica is surrounded by a cladding of lower refractive index, making a fibre usually 125 μm in diameter. The fibre is either multimode or single-mode (monomode). In multimode fibre the core is from 50 μm to 100 μm across. To maximise the bandwidth the refractive index profile of the core is graded from a peak in the centre reducing to the cladding index at the edge. The bandwidth of this type of fibre is typically 0.2 – 1 GHz.km. Single-mode fibre has a much smaller core, about 5 μm across, which is generally not index graded. Single-mode fibre has a much higher bandwidth, about 100 GHz.km, and is used on all new trunk telecommunications links in this country.

The attenuation of fibre is low in three wavelength regions (or windows); 3 dB/km at 850 nm, 0.4 dB/km at 1300 nm and 0.2 dB/km at 1550 nm. At 1300 nm single-mode fibre has zero nett dispersion, making it particularly suitable for high speed links. The low loss at 1550 nm makes it suitable for long distance links. High data rates are also possible, either by using narrow-linewidth sources to avoid dispersion⁷, or by developing fibre with the zero dispersion point shifted to 1550 nm⁸.

Optical telecommunications links normally remain undisturbed unless maintenance is required. However, in a studio centre, manual cross-plugging of routes may be required to supplement existing routes

on special occasions. An optical system would either have to allow manual cross-plugging or be sufficiently flexible to obviate its need. Connectors for multimode fibre are quite well developed with a typical loss of 1 dB, so could be considered for use in service. Single-mode connectors also have a typical loss of 1 dB when new, but are delicate so are not recommended. Further, they are expensive, and fitting them is a skilled and time-consuming task. Fusion splicing of all types of silica fibre is well developed with a typical splice loss of 0.2 dB, so repair of optical fibre is straightforward.

Until recently a semiconductor laser diode would have been the automatic choice for a link operating at 243 Mbit/s⁶. This is because lasers are inherently faster than LEDs. However, LEDs have now been developed that are capable of modulation above 100 MHz. The LED is cheaper and uses simpler control circuitry because it is less temperature-sensitive. A laser drive circuit must include both optical feedback and temperature stabilisation. On the other hand the output of an LED is divergent and the emitting region broad, hence it is difficult to couple to the fibre, particularly if the core is small. Typically a laser will launch 1 mW (0 dBm) into a 50 μm core fibre, an LED about 10 μW (–20 dBm).

Initially, sources were only available for the 850 nm window. Spurred by the lower attenuation of fibre at the longer wavelengths, manufacturers have developed suitable sources, although these are more expensive than their 850 nm equivalents. At 1300 nm and 1550 nm the low attenuation makes it possible to use an LED with single-mode fibre on a short interconnection.

A recent development is the distributed feedback (DFB) semiconductor laser⁹. This has a diffraction grating etched into the active layer of the device, Fig. 2. Bragg diffraction from the grating feeds light back towards the centre of the active layer, but only for a very narrow range of wavelengths. The spectrum therefore consists of a very narrow and stable single line, thus avoiding chromatic dispersion in single-mode fibre at 1550 nm. The DFB laser is intended for high speed links, wavelength-division multiplexing, and also coherent detection, which is described later.

An optical-fibre receiver consists essentially of a photodiode followed by an amplifier⁶. The photodiode may be a PIN-semiconductor diode or an avalanche photodiode. The choice of photodiode material depends on the wavelength used; silicon for 850 nm, and for longer wavelengths either germanium or a compound of elements from groups III and V of the periodic table. Germanium has a high dark current

and is very temperature sensitive, but the III-V compounds are still relatively new and have yet to reach their full potential.

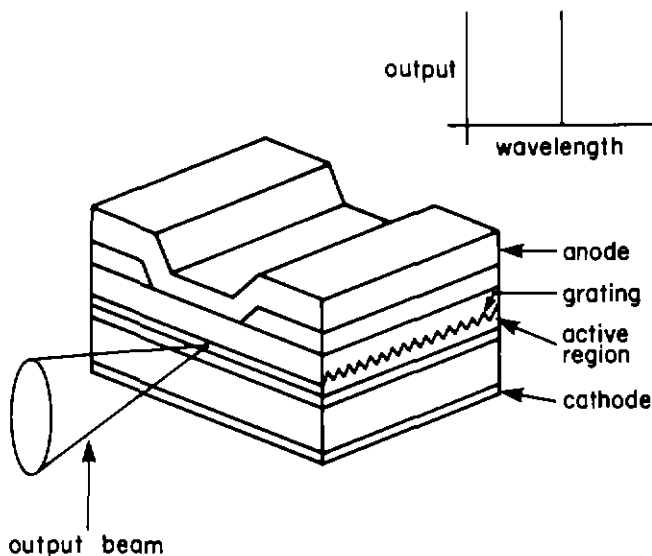


Fig. 2 - Distributed feedback laser diode chip.

The optical receiver is expected to detect signals as weak as 100 nW (-40 dBm), thus the first stage of amplification is critical. For this reason the photodiode may be combined with the amplifier in a hybrid package, so that parasitic effects are reduced. The first stage may be a high impedance FET amplifier, a transconductance amplifier, or the inherent amplification provided by an avalanche photodiode. The high impedance FET is the type most popularly used. It is an integrating amplifier, which increases sensitivity at the expense of dynamic range.

Thus, the optical signal must be arranged to have a minimal low frequency content. Packaged with the photodiode the hybrid is known as the PINFET. An avalanche photodiode will provide up to 10 dB of gain, and is the type most often used at very high data rates, although it is very sensitive to temperature and requires a high bias voltage.

Multimode optical systems working at 850 nm are the cheapest, partly because of their modest performance and partly because they use components whose manufacture is well established. However, regarding the fibre itself, single-mode fibre is now generally cheaper than multimode. Sources and detectors for single-mode systems are more expensive than their multimode equivalents, but development is continuing and this should reduce costs.

The range of optical components is varied, and new components are frequently introduced. It is, therefore, important to choose components that will

remain available over a long period to ensure a supply of spares. There is much research into optical local area networks¹⁰, and this should guide the selection of components for the digital video routing system.

A major consideration when designing a transmission system is the optical power budget. It is usual to draw up a formal table showing the power available from the source, the losses in transmission, and the power required by the receiver. A margin should be allowed for possible degradation in service. It should be noted that it is not yet practical to amplify optical signals to make up any short-fall in the power budget.

6. OPTICAL SWITCHING

Fibre-optics can readily replace coaxial cable as the transmission medium, but there remains the problem of switching the signals. Electrical switching is undesirable; optical transducers are expensive, consume power and take up space. This makes it worthwhile to consider switching the optical signal itself.

There are two main types of optical switch, mechanical and solid state. Mechanical switches depend on a moving element such as a prism, a mirror or even the fibre itself. A solid-state switch can in principle use any interaction with light. In practice four phenomena are commonly used; thermo-optic, electro-optic, magneto-optic and acousto-optic. They all require a medium such as a crystal within which the interaction may take place. Most solid-state optical switches are polarisation dependent, which complicates their design.

Solid-state switches can be further divided into two types, integrated-optical and discrete-optical. Discrete optical devices act on a free beam and would be placed between lenses to couple the light to the input and output fibres. Integrated optical devices confine the light to a waveguide, which itself becomes the interaction medium, and to which the fibres are butt coupled.

The performance of optical switches is characterised mainly by insertion loss and extinction ratio. Insertion loss is defined as the ratio of input power to output power with the switch on, expressed in decibels. Extinction ratio is defined as the power transmitted in the 'off' state divided by the power transmitted in the 'on' state, also expressed in decibels.

6.1 Mechanical-optical switches

Many designs for mechanical-optical switches have been proposed and constructed, some based on

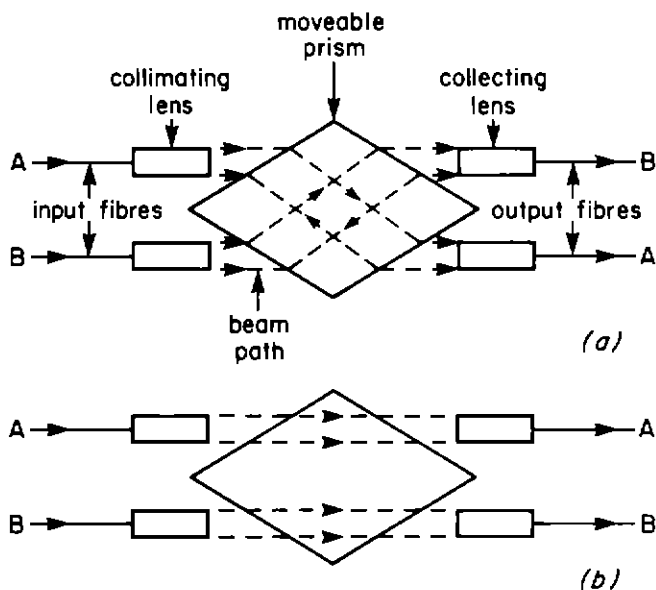


Fig. 3 - A 2×2 prism optical matrix:

- (a) prism raised into beam paths
- (b) prism lowered out of beam paths

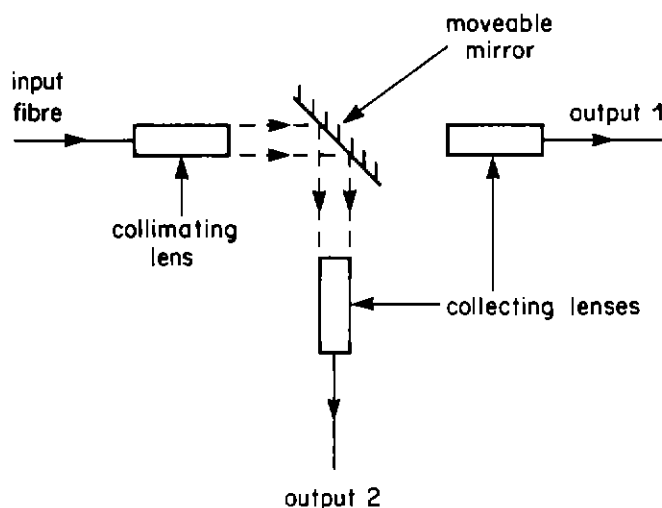


Fig. 4 - A 1×2 mirror optical switch.

prisms (Fig. 3), others on mirrors (Fig. 4) and some on moving fibres (Fig. 5). Almost all of them are restricted to multimode fibre because of the narrow tolerances and high stability required for single-mode fibre. The core of single-mode fibre is about six times smaller than that of multimode fibre.

Most mechanical-optical switches can only switch signals from one or two inputs to one or two outputs. Switch matrices approaching the size required for a studio centre have been produced¹¹, but these are not able to distribute the signal to several outputs at once. To do this either the power has to be split and fed to several switches or the switch itself has to be a partial power tap. Because nothing suitable was available commercially, some work was undertaken at Research Department.

An experimental switching matrix designed to work with multimode fibre was built. This matrix uses tailor-made components to maintain a low excess loss, Fig. 6. The matrix is a 10×10 crosspoint structure, and is fully described in another Report¹². This size is large enough to make a meaningful assessment of mechanical-optical switching. The main aim of this work was to determine the performance of a mechanical matrix, therefore only the most important parts were built to enable a representative set of measurements to be made. The longest path through the matrix and a 4×4 section including the shortest path were built.

The matrix operates by deflecting the light beam from the incoming fibres towards the outgoing fibres with mirrors, Fig. 7. A partially reflecting mirror at each crosspoint taps off a small proportion of the input beam, leaving the remainder to be distributed to other destinations as needed. The mirrors are moved into the beam using solenoids. Lenses are used to collimate the signal beams from the input fibres and to focus the switched beams onto the output fibres.

The matrix was found to be reliable. A double-mirror arrangement at each crosspoint reduces the effect of misalignment. Unlike electro-mechanical switches there are no contacts to become worn or dirty. However initial alignment of the beams within the matrix was difficult, because many of the adjustments, for example, mirror angle and lens position, are interrelated. The excess loss, that is, loss due to light scattered from the signal paths, in the 1×10 path was 7.9 dB, of which about 5 dB was due to incomplete coupling between the matrix and the fibres, the rest being due to imperfect alignment and scattering. Losses in the 4×4 sub-section were higher, this part of the matrix being significantly harder to align.

This work indicated that the largest practical matrix of this type is about 30×30 . However, of all types of optical switch, the mechanical-optical version is the only one that presently can give the required performance in terms of excess loss and extinction ratio. The power margin available presently in optical systems makes it very difficult to split an optical signal more than about 30 ways, given that some excess loss will occur in the splitting device¹³.

6.2 Discrete solid-state optical switches

The most familiar example of an optical switch is the liquid crystal type, as used in vast quantities in wristwatch and calculator displays. These switches act by changing the state of polarisation of the light, thus must be used with polarised light. In a watch or calculator this is achieved by facing the crystal with a

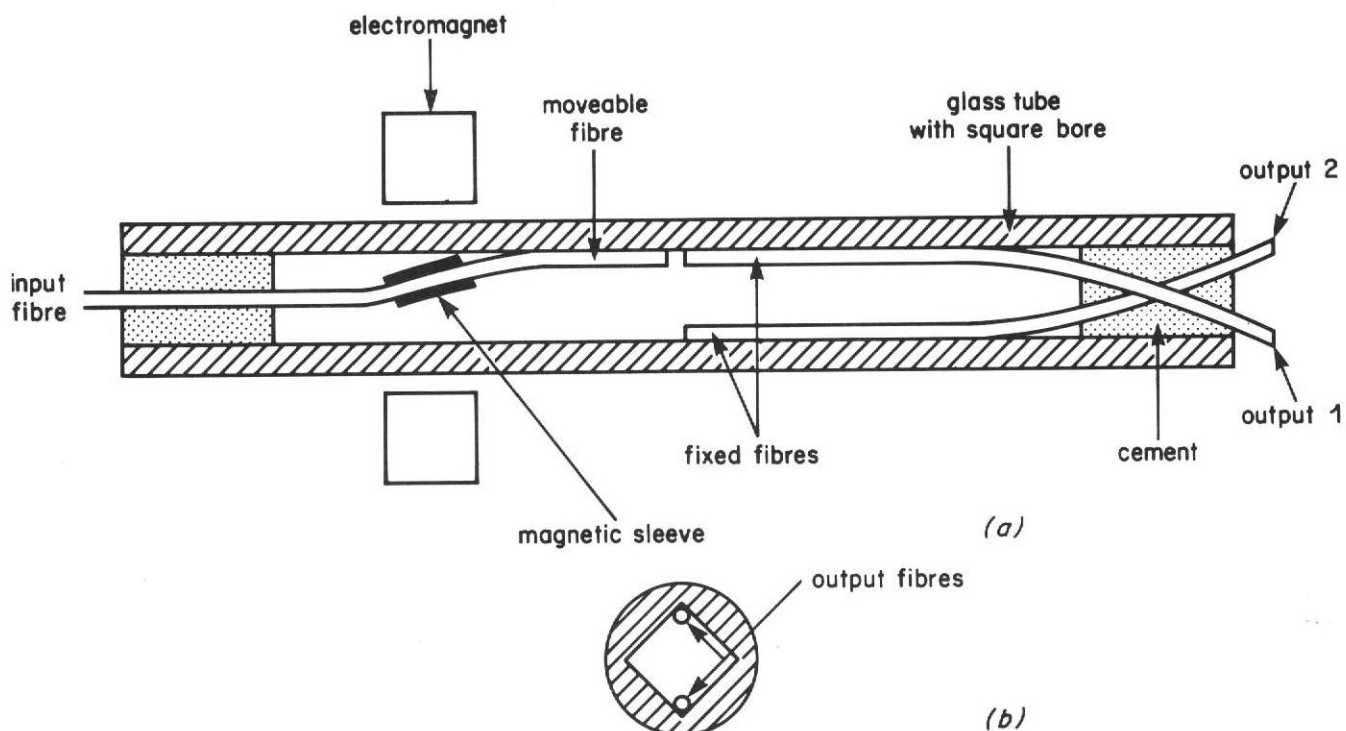


Fig. 5 - A 1×2 moving fibre optical switch:
(a) side view (b) cross-section

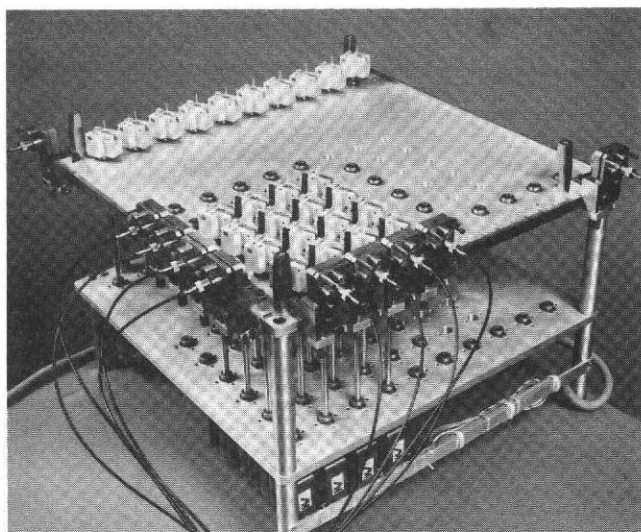


Fig. 6 - An experimental mechanical-optical switch.

polarising filter, which also acts as the analyser. A discrete liquid crystal switch suitable for use with fibre-optic systems is shown in Fig. 8. The two states of polarisation are switched individually. The complexity increases the difficulty of manufacture, and increases the insertion loss.

Other types of discrete solid-state optical switching are being investigated, such as holographic deflection¹⁴, but a device with performance adequate for very large switching networks has yet to be produced.

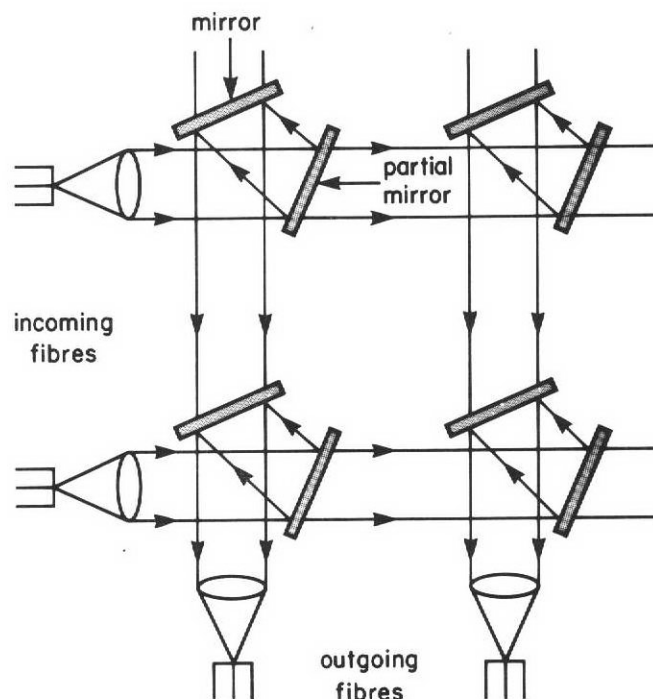


Fig. 7 - Mechanical switching and distribution matrix: principle of operation.

6.3 Integrated optical switches

Integrated optics is the study of the propagation of light in dielectric waveguide devices, and has been studied in detail in another Report¹⁵. In essence, it can be considered as the study of optical integrated circuits. The major advantage of integrated optics is

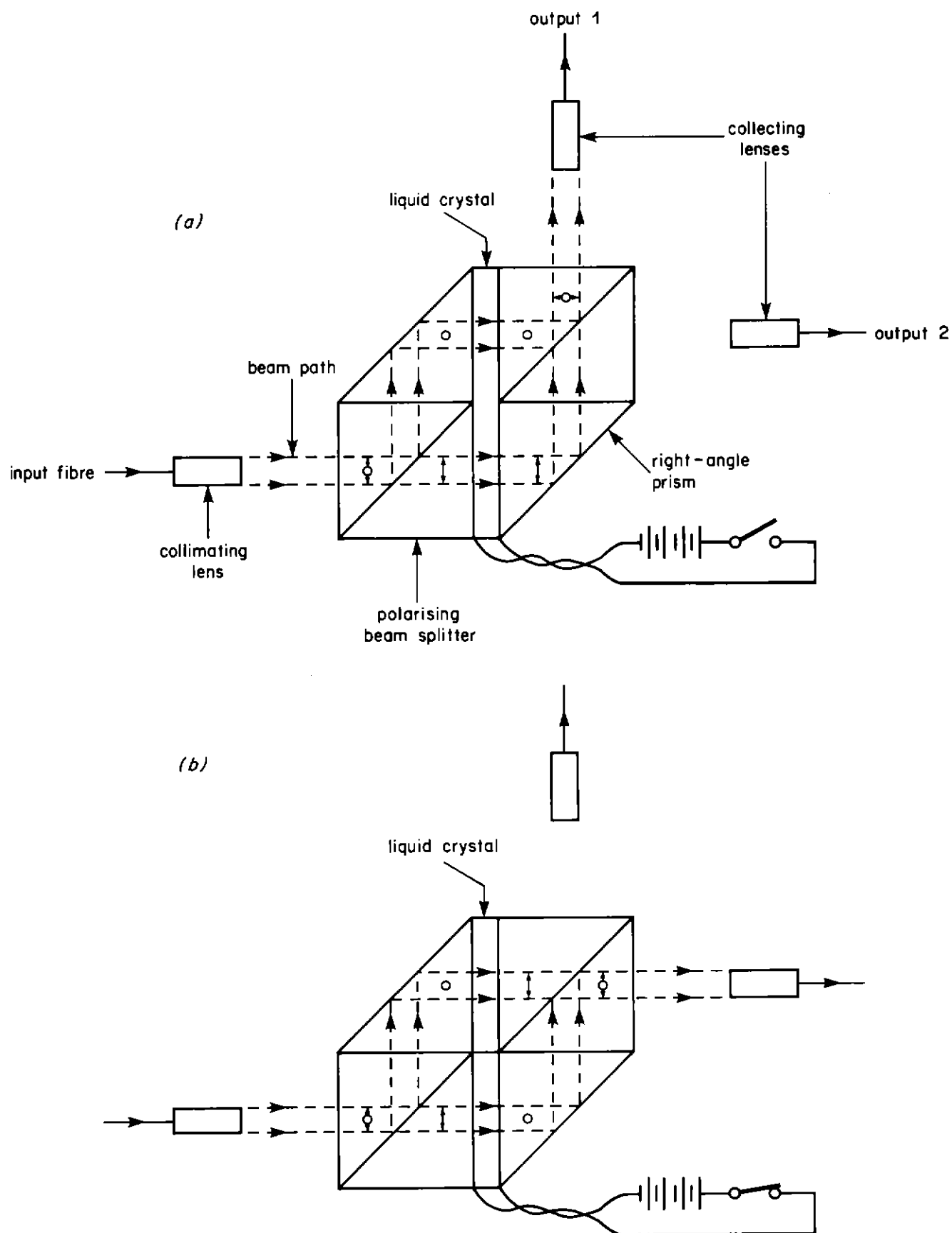


Fig. 8 - Liquid crystal 1 × 2 optical switch showing both switch states:

- (a) no rotation of beams in the liquid crystal
- (b) rotation of beams in the liquid crystal

that it allows optical signals to be manipulated by electrical signals without themselves being converted to electrical form. Furthermore, because the cross-sectional dimensions involved are small (typically micrometres) and the optical and electrical fields have a high degree of overlap, the voltages required are typically two orders of magnitude lower than for conventional optics. Consequently, integrated optics offers the possibility of high-speed (over 10 Gbit/s), low power (milliwatts) optical signal manipulation¹⁶.

The field of integrated optics has developed rapidly over the last ten years. A wide range of devices has been developed, including switches, modulators, splitters, couplers and tunable bandpass filters^{16,17}. Optical waveguides have been fabricated on a large range of materials, such as glasses, plastics, crystals and semiconductors.

The most widely used substrate material for active devices is lithium niobate. This material has a large electro-optic coefficient, which means that the control voltages required are particularly low, typically 5 – 50 V. However, because it is an insulator it can only be combined with sources and detectors in a hybrid form. In contrast, a substrate made from a semiconductor could combine the sources and detectors with the waveguide. Semiconductor integrated optics is considered in more detail in Section 6.4.

The most common method for making lithium niobate waveguides is titanium-indiffusion¹⁸, although other techniques have been demonstrated^{19,20}. The titanium-indiffusion process has been widely developed and is now reasonably well understood. The process can achieve low-loss (less than 0.3 dB/cm) waveguides²¹. Furthermore, the refractive-index profile can be matched to single-mode optical fibre to give insertion losses as low as 0.3 dB²².

However, there are a number of problems with the process. For example, optical damage to the material can occur at 850 nm, although this is not a significant problem at 1300 nm or 1550 nm²³. Two further problems restrict the packing density. Bends tighter than about 30 mm radius in the waveguide radiate significant amounts of optical power²⁴. The interaction length, which determines the minimum device length, can be several millimetres. Finally, loss in the waveguides is higher than in the bulk material: there is continuing effort to develop waveguides with smoother edges and with less impurities.

Various types of integrated-optical switch are under investigation. Generally, each design has attempted to improve one or two of the parameters, e.g. lowering the switching voltage. Much work needs to be done to produce a switch where all the

parameters are of acceptable quality. Initially switches based on a directional coupler, Fig. 9, were developed²⁵. Such switches show extinction ratios as good as -35 dB, but at the expense of insertion loss, which at 1.5 dB is too high for large matrices. Directional coupler switches are very long, so X-type switches, named after the pattern of their waveguides, have also been investigated, Fig. 10²⁶. However, with an extinction ratio of only -10 dB, X-type switch performance needs much improvement.

It has been calculated¹⁵ that crosstalk at waveguide intersections and poor extinction ratios would limit the size of an integrated optical switching array to about 10×10 . Subsequently, an 8×8 matrix has been demonstrated²⁷.

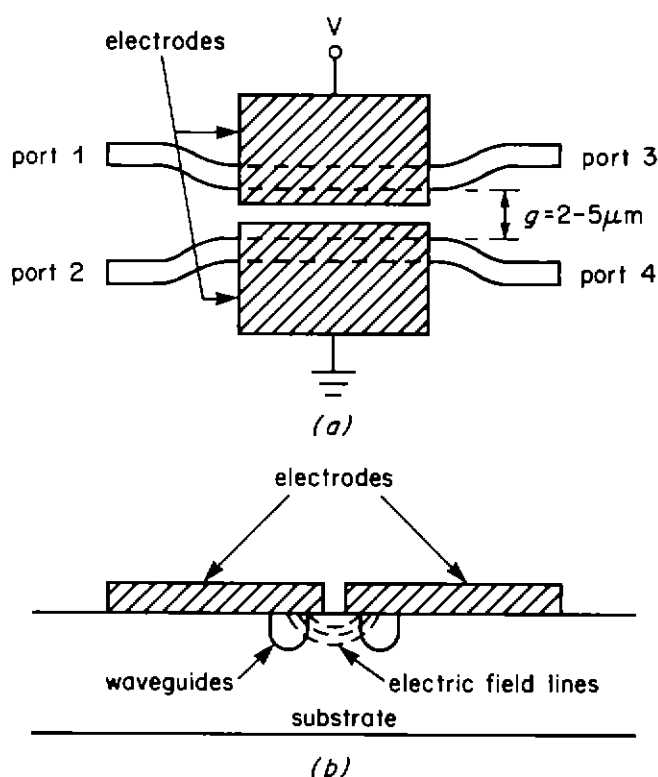


Fig. 9 - Integrated optical switch:

(a) top view (b) cross-section

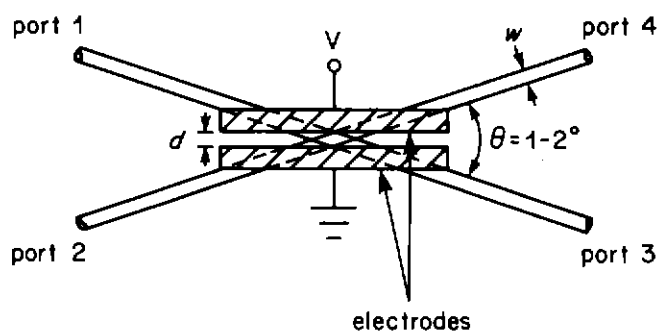


Fig. 10 - X-type integrated optical switch.

The processing technology will have to improve greatly to make a 100×100 array feasible. New techniques will have to be developed. For example, it has been suggested that waveguides be buried within the substrate so that they can cross with much reduced crosstalk. Hybrid regenerators could be used to link small arrays on separate substrates.

6.4 Semiconductor integrated optics

There has been much interest recently in the use of semiconductor materials for integrated optics, because of the potential for complete integration of the sources and detectors with the waveguide devices. Some progress has been made towards this, by combining lasers and waveguides with electrical components such as FETs²⁸. Advantage is taken of techniques developed for integrated circuit manufacture. Development has been rapid, and nearly all the devices made in lithium niobate have also been made in semiconductor materials such as gallium arsenide and indium gallium arsenide phosphide²⁹.

The performance of these devices approaches that of lithium niobate, although the two materials have different properties. For example, although the electro-optic effect in semiconductors is one sixth of the value in lithium niobate, the field overlap can be increased to compensate. This is because there is the ability in a semiconductor to vary composition and doping, and thus more closely control the field distribution. Losses at bends can also be reduced by this technique. Incorporating regenerators on the same substrate as the switch elements would allow non-ideal extinction ratios to be compensated. However, there are still major problems to be overcome, as the different devices can have contradictory requirements, for example, different substrate doping levels³⁰.

7. MULTIPLEXING

Multiplexing of several signals onto a single bearer is a technique that could be used to advantage in a studio routing and distribution network. Its most obvious effect is to reduce the amount of cable needed to carry a given number of signals. It also permits other topologies to be used, such as ring, star or bus arrangements, and this will be discussed in Section 8.

Multiplexing can take two forms; time-division multiplexing (TDM) and frequency-division multiplexing (FDM), usually referred to in optical systems as wavelength-division multiplexing (WDM). The amount of multiplexing with electrical transmission is limited by high-frequency loss in the cable. The bandwidth of optical fibre is many orders of magnitude higher (100 GHz.km for single-mode fibre at 1300 nm)³¹, although in practice a limit of a few

gigahertz would be set by the sources and detectors.

Space-division multiplexing (SDM) is a term sometimes used to describe the use of individual cables. On this basis the present routing system at Television Centre is an SDM system. However this is not true SDM, in which individual signals are identified by their spatial position in a common transmission medium. The term SDM is more appropriately used in optical parallel processing³², which is beyond the scope of this Report.

7.1 Time-division multiplexing

With time-division multiplexing the line rate is at least equal to the sum of the bit rates of the individual signals. Digital integrated circuits made from gallium arsenide are now available that can be operated at 2 Gbit/s³³. Silicon circuits capable of similar speeds are being developed. This would allow eight digital video channels to be multiplexed into a single data stream. Telecommunications organisations are developing optical transmission systems which can operate at bit rates of up to 8 Gbit/s³⁴. Such systems could carry over 30 digital video signals. However, this is still less than the 100 channels needed.

Time-division multiplexing imposes restrictions on the signals to be multiplexed. It is harder to combine signals if their bit-rates or formats are different, and it must be possible to guarantee that bit rates do not go outside predetermined limits.

7.2 Wavelength-division multiplexing

Several optical signals can be multiplexed onto a single optical fibre by transmitting them at different optical wavelengths. A significant advantage of wavelength-division multiplexing is that, unlike time-division multiplexing it places few restrictions on the signals to be multiplexed. Digital signals can have different formats and bit rates, and if necessary analogue and digital signals can be mixed. (Analogue transmission on optical fibre is usually avoided however, except for non-critical signals, because of the difficulty of maintaining linearity). Thus in a studio centre some wavelengths could be reserved for composite or high-definition signals. Another advantage is that the line rate nowhere exceeds the highest individual bit rate.

A wide variety of WDM systems has been demonstrated^{35,36}, based on multimode and on single-mode fibre, operating in the 800–950 nm region, the 1300–1550 nm region, or both.

The most critical component in a WDM system is the demultiplexer. Its ability to resolve

different wavelengths, and to some extent its insertion loss, will be major factors determining the number of channels.

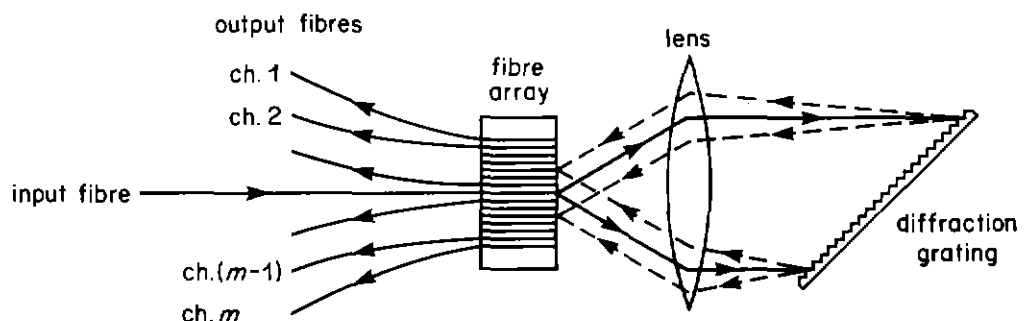
Some types of demultiplexer can also be used as multiplexers, simply by reversing the direction of the light. Alternatively, the multiplexer can be a conventional optical-fibre coupler.

The spectral linewidth of each source must be sufficiently narrow to avoid crosstalk, and the sources themselves must have stable operating wavelengths. Therefore, almost all WDM systems use laser sources.

The most promising demultiplexer designs are based on diffraction gratings, Fabry-Perot etalons and interference filters^{35,36}. However, the WDM systems demonstrated so far are limited to about 20 channels, which is insufficient for a studio centre.

The diffraction grating demultiplexer³⁷ has a high selectivity allowing channels to be spaced as closely as 1 nm in single-mode fibre. This is because the end of a single-mode fibre is a good approximation to a point source. A typical arrangement is shown in Fig. 11.

Fig. 11
Diffraction grating
wavelength demultiplexer.



The grating separates the wavelengths, so that there is simultaneous access to all channels, if needed. A single-channel tunable demultiplexer can be made by rotating the grating to direct the desired channel to a single output. Fibres are usually used to collect the demultiplexed beams because there is not enough space to place the detectors directly in the beams. These fibres can be multimode to increase the collection efficiency, since they are normally so short that there would be no significant dispersion. Excess loss of optical power in such demultiplexers is typically 3 dB. The mechanical rigidity must be very high when very narrow channel spacings are wanted, and this may involve the use of temperature stabilisation.

A Fabry-Perot etalon consists of two opposing highly-reflecting mirrors with a small gap between them to form a resonant cavity, Fig. 12³⁸. By

mounting one mirror on a piezo-electric transducer the gap can be varied to tune the etalon. The wanted channel passes through the etalon and the others are reflected. Optical isolators may be needed to prevent the reflected channels causing any instabilities in the optical source. Because the unwanted channels are reflected, a Fabry-Perot etalon is limited to applications where only one signal is to be extracted from the multiplex.

The spectral response of an etalon has the characteristic comb shape of a resonator, Fig. 13. The ratio of the spacing of the transmission peaks to their half-power width is called the finesse. A tunable etalon with single-mode fibre connections has recently been reported³⁹ with a finesse of more than 260. The effective finesse could be increased to about 520 by the use of simple edge filters. Higher finesses would require etalons to be cascaded.

Dielectric interference filters can be used when only a few widely spaced channels are required. They consist of a series of dielectric layers either on a glass substrate, or deposited onto the end of the fibre itself, as shown in Fig. 14⁴⁰. Such filters are mostly used with multimode fibre.

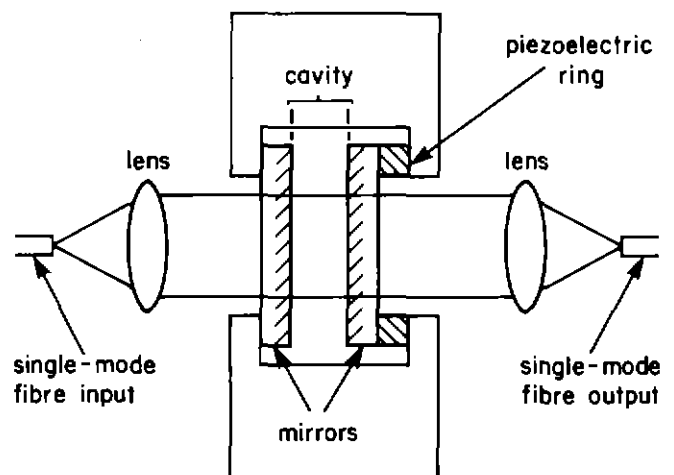


Fig. 12 - Fabry-Perot wavelength demultiplexer.

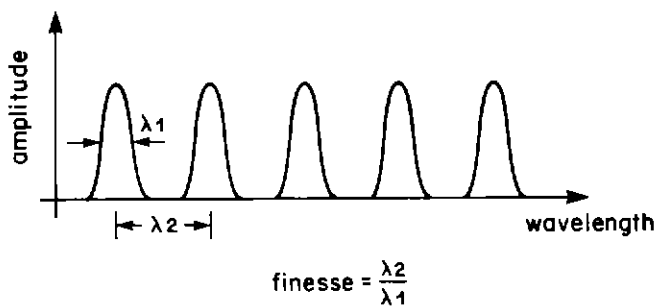


Fig. 13 - Spectral response of Fabry-Perot etalon.

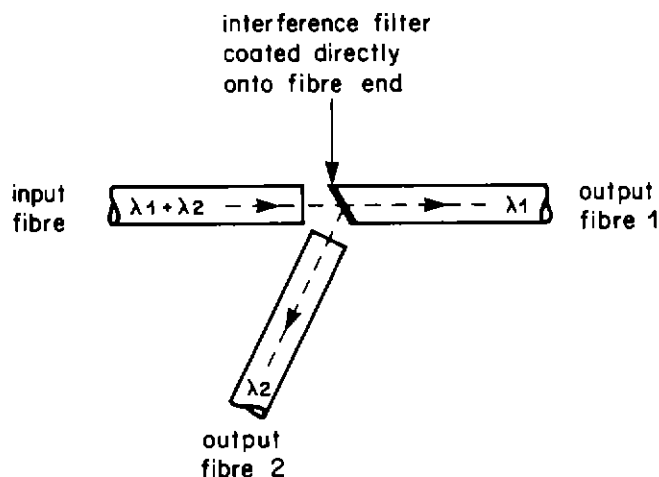


Fig. 14 - Interference filter wavelength demultiplexer.

7.3 Coherent detection of wavelength-division multiplexed optical signals

Coherent detection is a well known technique in radio receiver design which has been adopted for the detection of optical signals. It allows channels to be spaced close to the Nyquist limit in a WDM system. Also, it has been shown that it can improve sensitivity over direct detection by up to 20 dB⁴¹. Two lasers are needed, one to transmit the signal, and one to act as the local oscillator in the receiver, Fig. 15. The output of the local oscillator is combined with the received signal in a fibre coupler and the resulting beam falls onto the detector. Mixing occurs because of the square-law transfer characteristic of a photodiode. The wavefronts of the signal and local oscillator have to be the same shape for efficient mixing. A single-mode fibre coupler must, therefore, be used to combine the signals, which implies the use of single-mode fibre to transmit the signals. Multimode fibre is unsuitable because the wavefront is scrambled.

As in a radio receiver, the local oscillator frequency can be the same as the signal frequency, (homodyne detection), or different, (heterodyne detection). Homodyne detection requires a receiver bandwidth no greater than the signal bandwidth, but the local oscillator has to be phase locked to the signal

carrier. With a laser this is very difficult to achieve for more than a few minutes at a time. In heterodyne detection small fluctuations in phase are acceptable, provided that the rate of change of phase falls outside the intermediate frequency (IF) band. However, the receiver bandwidth must be large enough to respond to the IF and its sidebands.

It is not possible to use conventional laser diodes in a coherent system. Their spectrum consists of a series of emission lines covering about 6 – 9 nm. A coherent system requires the linewidth to be sufficiently narrow that it may be treated like a tuned carrier⁴².

The most promising optical source is the DFB laser described in Section 5. The DFB laser produces a narrow emission line and can be modulated at high data rates. Some types can be tuned by about 5 nm, either by varying the temperature⁴³, or, with certain modifications to the laser, by varying the current⁴⁴. In electrical terms the tuning range is equivalent to about 900 GHz, which would provide 3600 channels in theory. The principal problem is stabilising the frequency and the phase of the laser emission to the narrow tolerances required of coherent detection.

Because DFB lasers have only recently become available, most research on coherent detection has used external-cavity lasers. There are various types^{45,46}, and a typical arrangement is shown in Fig. 16.

Essentially, an external-cavity laser consists of a semiconductor laser chip with one facet anti-reflection coated, and optical feedback provided by a diffraction grating or mirror. The wavelength is tuned by changing the cavity length, by rotating the grating, or both. A rotatable glass plate may provide fine adjustment of the cavity length. A long cavity produces closely spaced modes, so a tunable Fabry-Perot etalon may be introduced into the cavity to act as a mode selector⁴⁷. Controlling the temperature of the laser diode can also be used to tune the operating wavelength. External-cavity lasers can be made with a tuning range of 55 nm at 1.5 μm ⁴⁸.

The size of the external-cavity laser and the fact that it is made from separate optical components makes it susceptible to vibration and temperature changes. This makes it less suitable than the DFB laser for operational use.

8. NETWORK TOPOLOGY

The topology of the network is the arrangement of its interconnections. Topology is not concerned with the means by which the interconnections are made, their relative or absolute lengths or the routes that they take through the building. It cannot therefore be

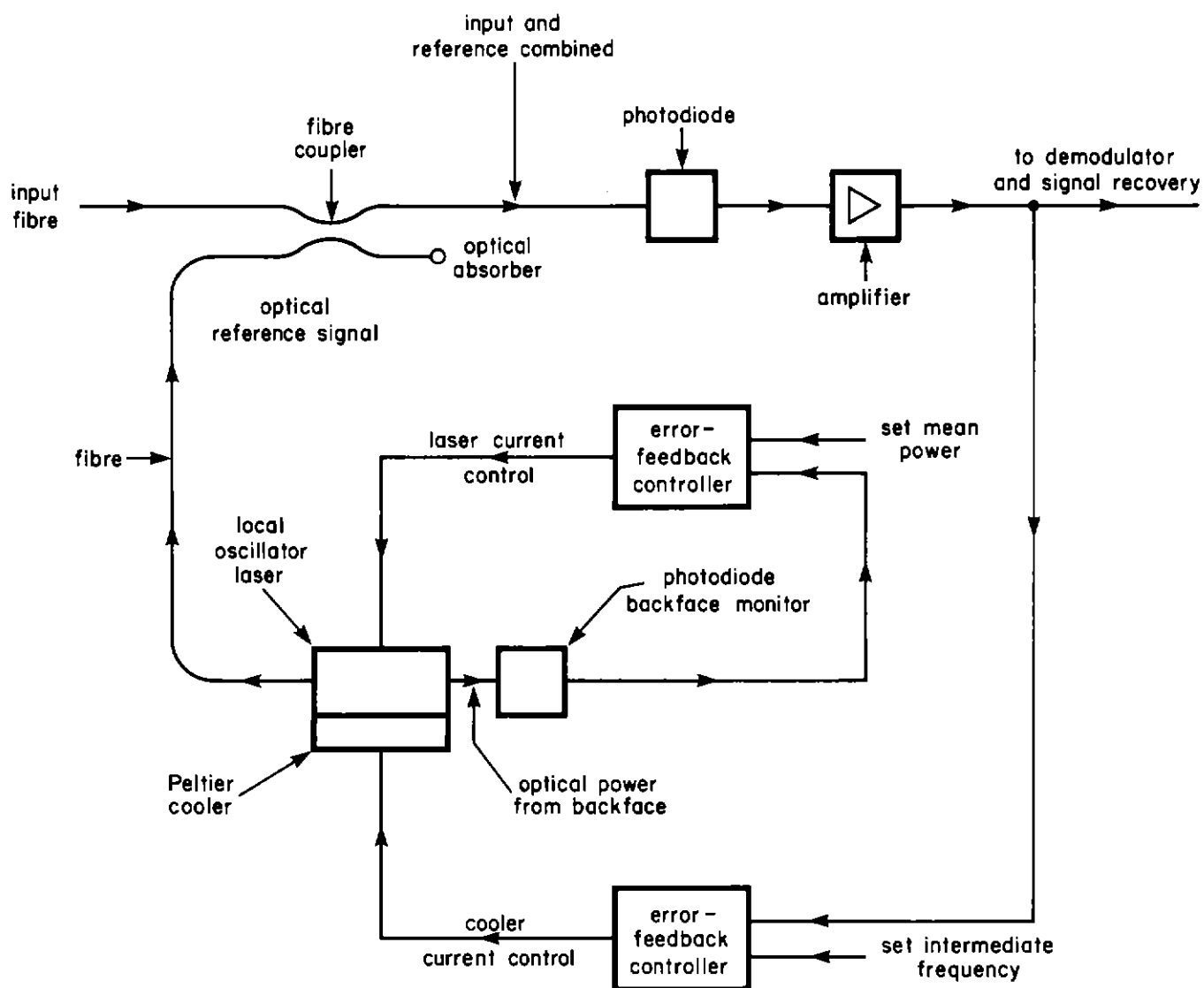


Fig. 15 - A coherent optical receiver.

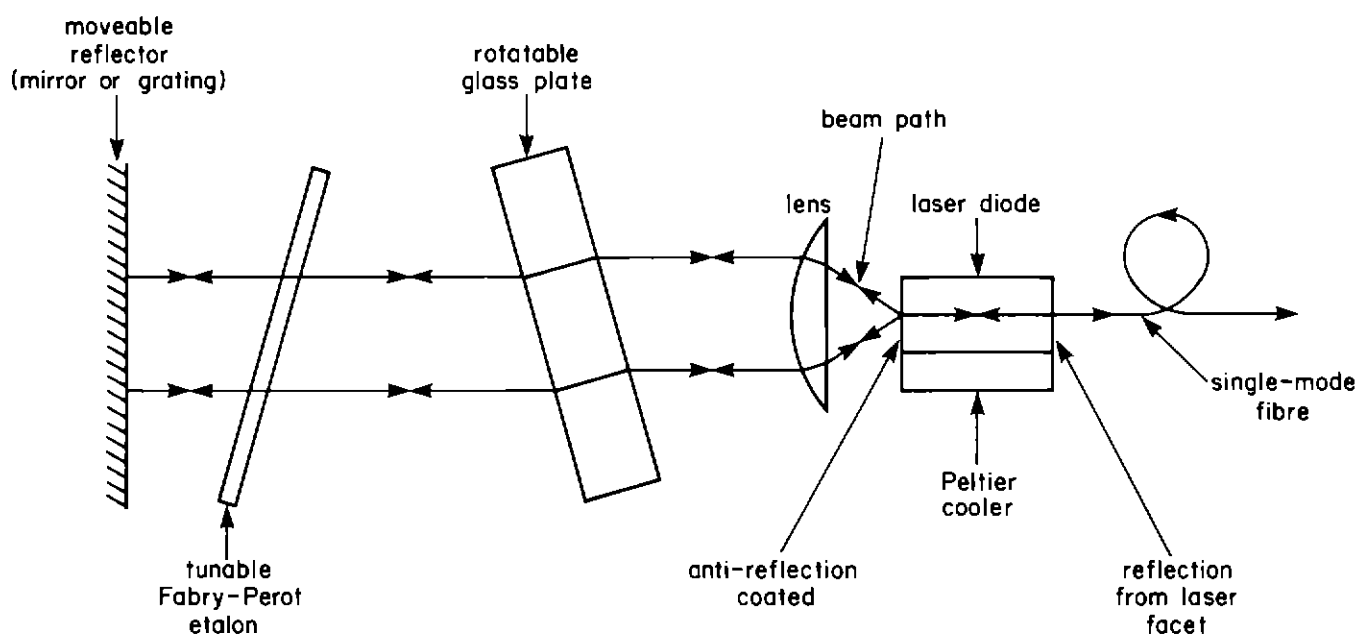


Fig. 16 - External-cavity laser.

inferred from the physical location of equipment, nor does the placing of equipment dictate the topology, although it may strongly influence it. The network topology will help to determine the capacity of the network, its modes of failure, and will also influence the type of control and location of control points.

The routing and distribution system in Television Centre is a switched star network, but other network topologies which can be considered are tree-and-branch, ring, and passive star.

8.1 Switched star

The switched star arrangement, Fig. 17(a), was chosen for Television Centre because of its ability to connect any source to any destination. The capacity of the system is high; provided the switching matrix at the centre of the star is non-blocking, all sources and destinations can be continuously active, an essential requirement of a studio routing network.

Such a network is amenable to centralised control, as at Television Centre, where a formalised booking procedure for circuits is operated.

8.2 Tree-and-branch network

A tree-and-branch network consists of a central switching area, with links to other self-contained switching areas, Fig. 17(b). This type of network could be used in an 'island studio' distribution and routing system. In an island studio system, each studio is self-contained, having its own facilities such as video tape recorders and telecines. Island studios are attractive because equipment is available without prior booking. The studio output is therefore a fully assembled programme, suitable for immediate transmission.

The main advantage of the tree-and-branch network is that the main switching matrix is only required to route signals between studios and for contributions to and from outside sources. It can be much smaller because the switching operations are distributed amongst the islands. The size of matrix required may fall within the range of present optical technology.

A common criticism of the island studio system is that it is expensive because each studio has a full complement of equipment which is not always fully used. Maintenance will be difficult as equipment of the same generic type will be distributed throughout the studio centre. However, it is possible to compromise and locate expensive equipment such as video recorders in their own areas, but dedicate each machine to one studio. In case of failure a replacement machine is more easily provided.

8.3 Ring network

A ring network consists of a main signal link or bus routed round all the areas in the distribution system, Fig. 17(c). At each node, items of equipment transmit or receive signals from the bus. The signals are multiplexed on to the bus in either the time or frequency domain or both.

There are a number of advantages. First, signals from all sources are distributed to all destinations, making it easy to arrange for sources to be selected at destinations. Secondly, new access points can be added to the ring network simply by creating a new node.

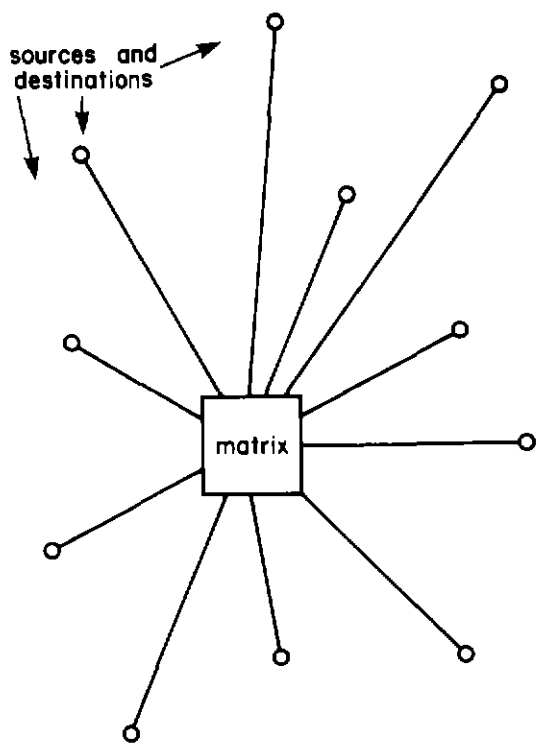
The main disadvantage in a studio centre would be the high data rate on the ring, of the order of 25 Gbit/s. This is well beyond electrical capabilities, and would require both time and wavelength multiplexing to allow optical transmission to be used.

However, optical transmission is not suitable for a ring network. This is because there is no optical equivalent of the high impedance tap, that is, a tap which allows both a small amount of optical power to be tapped from the ring to receive a signal, while having a high coupling efficiency for signals added to the ring. Alternatively, there is no acceptable optical amplifier which could compensate for power tapped from the ring. Electrical regeneration of the optical signals would require a large number of electro-optic interfaces each capable of handling the entire traffic on the ring.

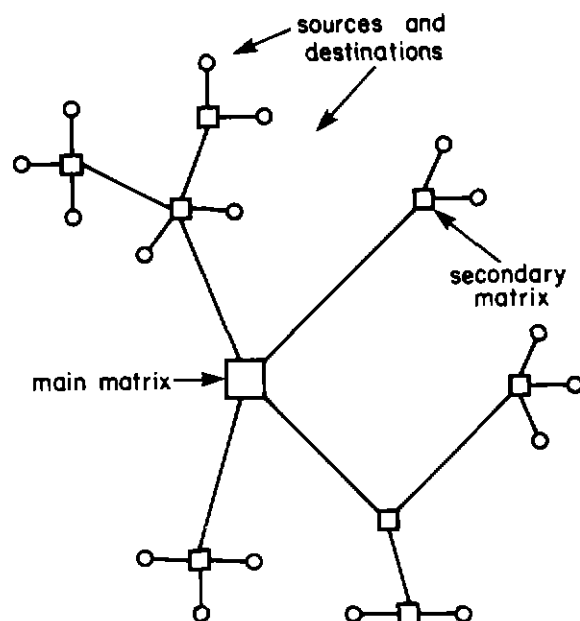
8.4 Passive star network

A passive star network is shown in Fig. 17(d). Each source sends its information to a central point where it is passively divided then sent on to every destination. TDM, FDM, WDM or coherent transmission can be used to increase the capacity of the system. Even so, electrical transmission used alone would require many cables in parallel. A passive star network is very well suited to fibre-optic transmission. It has the advantage that the optical signals do not have to be switched to perform the routing.

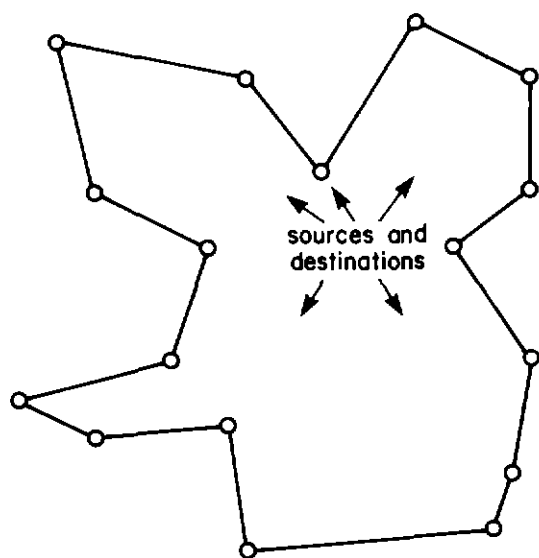
An optical passive star network would consist of a fibre from each source connected to an input of a star fibre-coupler⁴⁹. Each of the output fibres would receive an equal fraction of all of the input signals. Each source would transmit on its own unique wavelength to allow sources to be selected by wavelength demultiplexing. The system would need to be based on single-mode fibre to achieve low losses and closely spaced wavelengths.



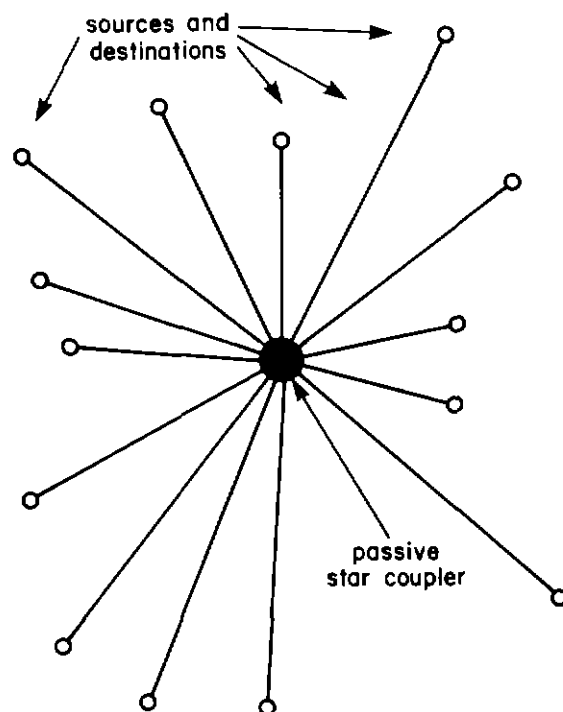
(a)



(b)



(c)



(d)

Fig. 17 - Network configurations for interconnecting sources and destinations:

- (a) switched star network
- (b) Tree-and-branch network
- (c) ring network
- (d) passive star network

Because the star coupler both multiplexes the signals and distributes them, its performance is critical to the system. The splitting ratio should be insensitive to wavelength, and the excess loss should be low to permit the signals to be distributed as widely as possible. These criteria can be satisfied by constructing the star coupler from 2×2 couplers. As an example, a 16×16 coupler is shown in Fig. 18⁵⁰. Such couplers are now available to a very high standard, with excess losses as low as 0.05 dB⁵¹ and a wavelength-dependent loss variation of about 0.05 dB.

The maximum size of the network depends on the insertion loss that can be tolerated, given that the optical power must be shared between all the destinations. Allowing an insertion loss of 25 – 30 dB permits the network to serve about 32 sources and 32 destinations. (Making the number of channels a power of two makes most efficient use of the array of couplers). This leaves adequate power to overcome losses due to connectors and other components in the system.

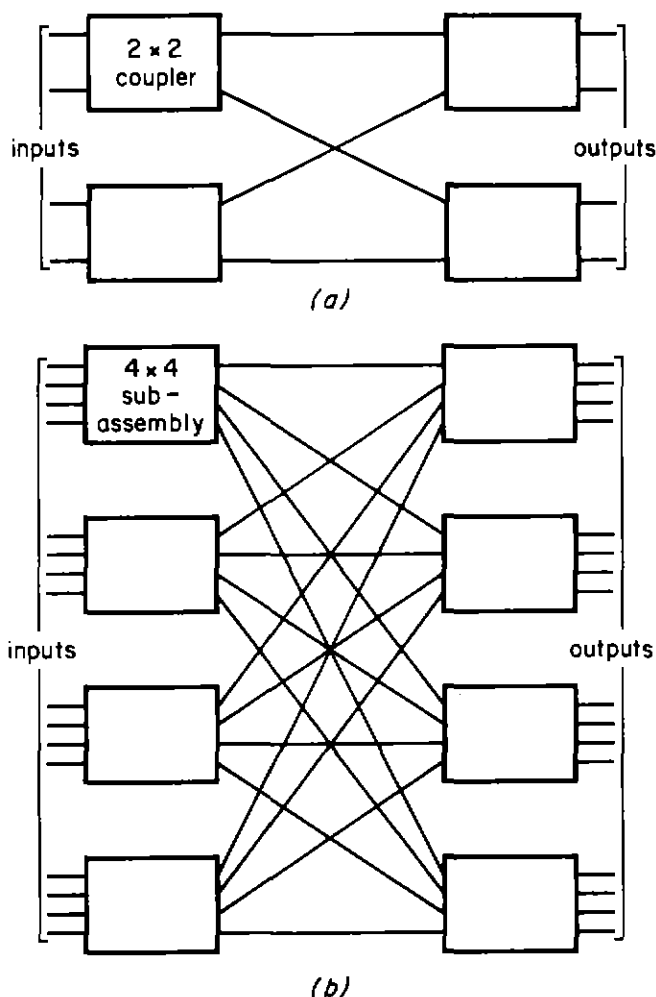


Fig. 18 - Combining 2×2 fibre couplers to form a 16×16 coupler:

- (a) 4×4 assembly made from 2×2 couplers
- (b) the complete coupler

8.5 Control of the routing network

Presently, at Television Centre, a request to set up a route is handed to Central Area Bookings for a line to be reserved. There, the line requirements for each day are collated, and printed information is sent to the Central Apparatus Room staff who select routes on a switch panel at the appropriate times. In practice routes are needed at short notice, or late changes have to be made. The new instructions must be telephoned to the Central Apparatus Room.

A routing system is more convenient to use if destinations could select sources themselves. Systems that distribute all sources to all destinations, such as ring or passive star systems, are well suited to this type of operation. Switched star or tree-and-branch systems would require special arrangements for the distribution of the control signals if destination control was desired.

Presently at Television Centre, uniselectors give sixteen levels of switching for the sound and ancillary signals associated with each video signal. Multiplexed systems give the possibility of carrying these signals along with the video, thus obviating the extra levels of switching. However, to enable easy identification of the sound and ancillary signals, a suitable method of labelling would need to be found. The use of a video tape recorder illustrates the problems involved. The remote control signal for a video tape recorder would be sent in the opposite direction to the video signal. Also, although many destinations may monitor the output of a tape recorder, only one destination should have control of the machine.

9. OPTIONS FOR A LARGE VIDEO ROUTING AND DISTRIBUTION SYSTEM

The techniques just discussed can be combined in a number of ways to provide a large routing and distribution network, as indicated in Table I. Noteworthy combinations are discussed in this section by reference to the corresponding section numbers shown in the table. The discussions centre on the suitability of each option for a studio centre, with particular regard to practicality, cost and timescale.

9.1 Electrical transmission in parallel format with electrical switching

Parallel transmission is technically the simplest option. It is expected that digital video equipment will be fitted with parallel interfaces complying with Recommendation 656. Small groups of equipment will probably be interconnected with this interface, as has been seen at recent demonstrations⁵².

Table 1
Possible combinations of transmission and routing techniques

Routing or switching technique	Transmission method				
	Electrical parallel	Electrical serial	Optical multimode LED	Optical multimode laser	Optical single-mode
Electrical switching	(9.1)*	(9.2)	(9.3)	(9.3)	(9.3)
Discrete optical switching	—	—	—	(9.4)	—
Integrated optical switching	—	—	—	—	(9.5)
Wavelength division multiplexing (WDM)	—	—	(9.6)	(9.6)	(9.7)
Time-division multiplexing (TDM)	—	—	—	—	(9.8)
Coherent	—	—	—	—	(9.9)
TDM and WDM	—	—	—	—	(10)

* Report section number where discussed, e.g. (9.1)

The Design Group of BBC Design and Equipment Department has developed a range of components for a parallel transmission network⁵³. The cable contains nine twisted-pair conductors and is about 10 mm in diameter.

To reduce timing errors between individual bit-signals the cable is constructed so that the twisted pairs are the same length. The cable is screened to reduce crosstalk. The interface has been demonstrated for distances up to 200 m without regeneration.

The connector specified in Recommendation 656 is the 25-way subminiature D-type. This is widely

used, particularly by the computer industry, and is readily and cheaply available. However it is not regarded as satisfactory for a patch-panel connector. A more rugged alternative has been developed, based on a PCB edge-connector.

The concentration of parallel signals at a central switching matrix is seen to be a serious problem. To attempt to avoid this problem Design Group has also investigated a matrix in which each signal is serialised into two signals of 108 Mbit/s each. A capacity of eight sources and sixteen destinations was achieved within a 178 mm high (4-Unit) panel, not including power supplies and control logic.

9.2 Electrical transmission in serial format with electrical switching

Although the serial interface defined by Recommendation 656 is harder than the parallel interface to implement, a single signal is easier to transmit and switch.

Research Department has investigated serial electrical transmission, using standard video coaxial cables. The study showed that the serial waveform could be transmitted about 200 m before the bit-error rate became unacceptable. The study included both the effects of high frequency loss and crosstalk from a neighbouring cable. However, more measurements of crosstalk from a large number of cables need to be performed. These results have been confirmed by experiments carried out by Design Group.

In the Research Department experiments a receiver was built, capable of up to 30 dB of equalisation at 100 MHz. Although of relatively simple design, it was able to recover isolated 'ones' in a series of twelve 'zeros'. This is more than adequate for the 8B9B code defined in Recommendation 656.

Switching was investigated by building equipment to simulate the longest path through a 100×100 switching matrix. The matrix was based on sixteen-to-one data selectors, interconnected as shown in Fig. 19 to form a 120×152 matrix. In the simulation the selectors were grouped four to a circuit

card. The signals were distributed to the circuit cards along backplanes. A complete matrix would contain 304 such cards mounted in 16 racks.

Most of the circuit cards were simulated by loading the backplane transmission line with the correct impedance at the appropriate positions. The signal also passed through eight selectors. The circuit was found to work satisfactorily at up to 265 Mbit/s (the limit of the test equipment available).

Large parts of the serial interface are amenable to large-scale-integration. At present only the serialiser and deserialiser themselves are available. This still leaves 8B9B transcoding, line receiving, equalisation, and clock recovery to be performed by discrete circuitry.

9.3 Optical transmission with electrical switching

A system which combines optical transmission with electrical switching avoids the difficulties of optical switching. By current standards of optical fibre transmission the interconnections in a studio centre are very short, and the use of electrical switching means that no additional constraints are placed on the optical performance.

In these circumstances an LED would provide a simpler and cheaper solution than a laser, which would usually provide far more power than is actually

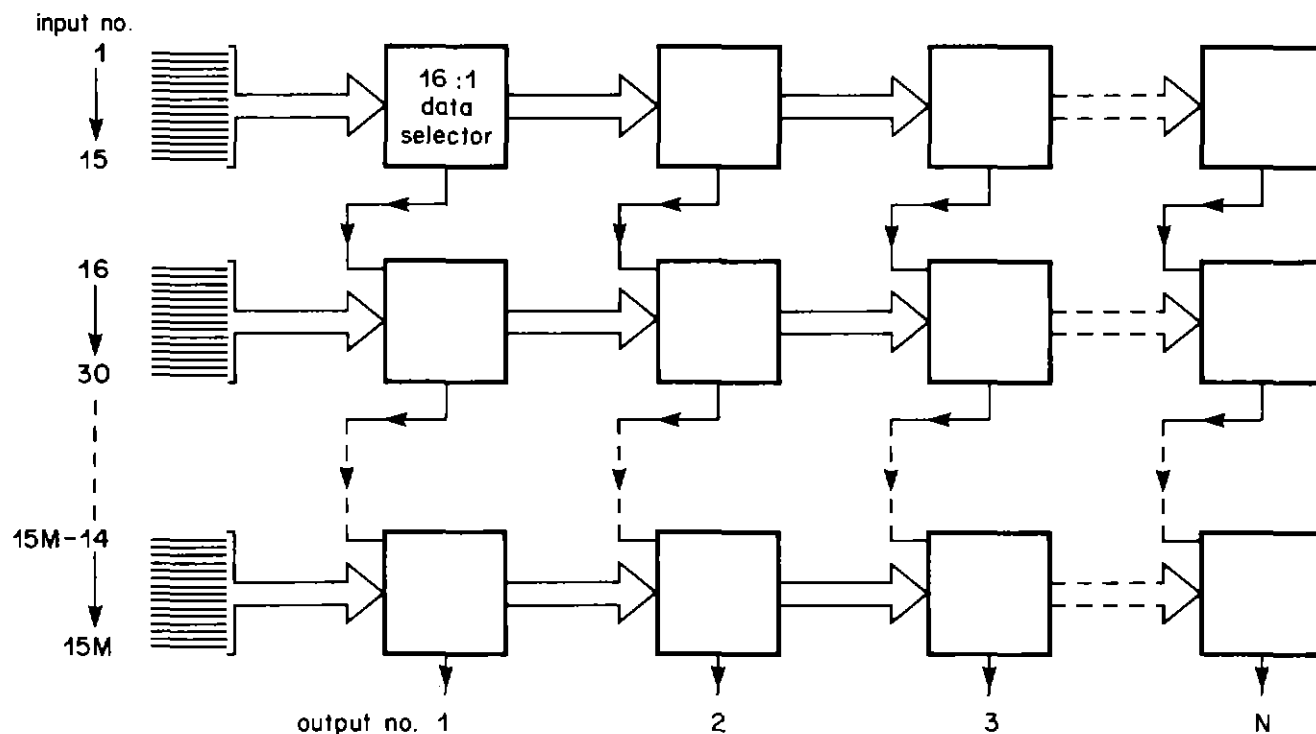


Fig. 19 - Electrical matrix made from 16×1 multiplexers.

needed. The optical power available from an LED is adequate provided care is taken to limit optical losses, for example by restricting the number of connectors. The system could use single-mode fibre. It would be the best long-term choice because it is increasing in popularity and it would allow the system to be upgraded in the future, for example by adopting WDM or coherent detection.

If losses are too large, the launched power could be increased by using a multimode fibre. For example, a core diameter of 50 μm would increase power levels by 10 dB, and 100 μm -core fibre would provide about a further 6 dB. Larger fibres are precluded because the fibre chosen should have a distance-bandwidth product of at least 100 MHz.km.

An LED link would operate at 1300 nm rather than 850 nm. Fibre loss and chromatic dispersion are reduced, and LEDs for 850 nm are not fast enough to carry 243 Mbit/s.

9.4 Optical transmission with discrete-optical switching

The main purpose of optical switching is to avoid the expense of converting the signal between optical and electrical form. However, an optical switch is not lossless, and therefore can only be used when there is sufficient optical power. Further optical losses are incurred by splitting the signal for distribution to multiple destinations. The use of a laser is essential, and even then the power margin is not sufficient to allow the signal to be switched more than about 30 ways.

Therefore, while a system based on optical switching would be adequate for a small installation, regenerators or optical amplifiers would be essential in a system for a large studio centre. In the timescale for the replacement of the routing system at Television Centre, regenerators are unlikely to be available at a reasonable cost, given the large numbers needed, and direct optical amplifiers are unlikely to be sufficiently developed.

9.5 Optical transmission with integrated optical switching

It is not thought likely that integrated-optical devices will be developed in time for the installation at Television Centre. Those components that are becoming available, principally modulators and switches, are relatively simple and could not form the basis of a large network.

However, integrated-optical techniques for switching and processing optical signals are the subject

of much research throughout the world. There is no doubt that the formidable problems of this technique will eventually be solved. In the long term, integrated optical switching is probably the most attractive option if the existing switched star arrangement is retained.

The devices will probably be based on semiconductor materials. Although most experimental work has concentrated on lithium niobate, the potential for semiconductor integrated optics is greater. A semiconductor integrated-optic array could incorporate regenerators, and thus give a practical solution of the array problem sooner than lithium niobate.

9.6 Wavelength-division multiplexing on multimode fibre

The main reason for considering a multimode system is cost. Detectors and lasers working in the 850 nm window can be used, and these are relatively cheap.

Although wavelength multiplexing is possible on multimode fibre, the number of channels that can be provided is small. A laser-based system can have about six channels, an LED-based system only two or three. In practice, the insertion loss of the multiplexer and demultiplexer would diminish the power margin of the LED-based system below an acceptable level.

The extra power of the laser would give adequate power margins (about 25 dB), and it is possible to devise a passive star network that takes advantage of this power. Such a system is shown in Fig. 20. The wavelength demultiplexer will lose about 3 dB, leaving sufficient power to split the signal about 16 ways.

Thus the system is based on four wavelengths, split 16 ways. Fig. 20 shows two types of optical receiver. The first option uses four wavelength demultiplexers and sixteen optical detectors, which is expensive but has no moving parts. The second option uses an optical switch and a tunable wavelength demultiplexer, thus saving on optical components. The loss through the switch would have to be small because there is little power to spare.

The system has the capacity to route only 16 channels. Eight such systems in parallel, linked by additional electrical switching, would be needed for the installation in Television Centre.

9.7 Wavelength-division multiplexing on single-mode fibre

Single-mode fibre is better suited than multimode fibre to WDM systems. When the basic

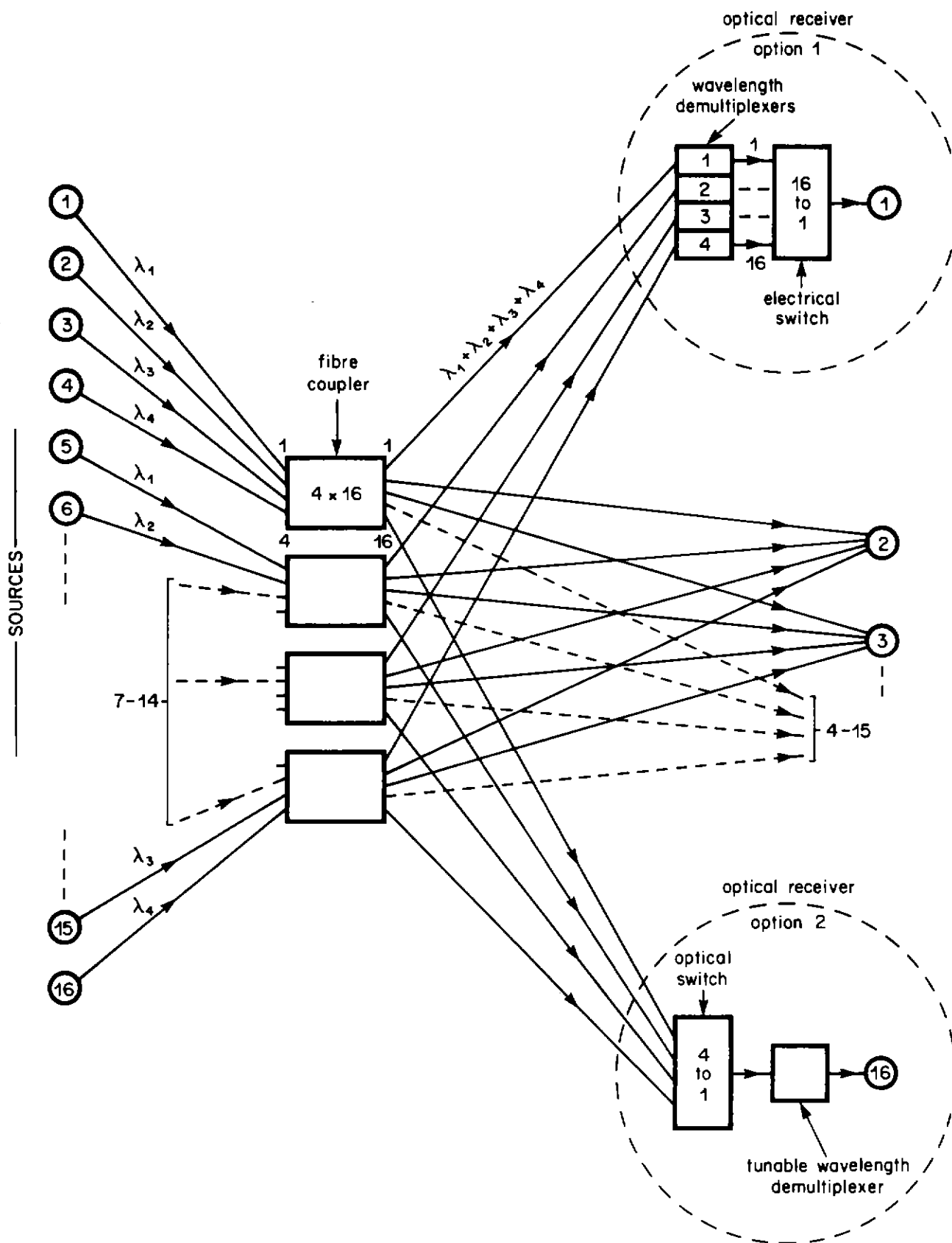


Fig. 20 - A WDM system with multimode fibre.

principles described in Section 9.6 are applied to single-mode fibre bigger routing systems can be formed. Such a system is shown in Fig. 21. The network is based on a passive star coupler, which combines the signals from each source (at unique wavelengths) and then divides the combined signal between all the destinations. The sources are selected at the destinations by optically demultiplexing.

At each destination a Fabry-Perot etalon is used to select the required source. British Telecom have developed a compact, robust design, based on a single-mode connector⁵⁴.

Four systems in parallel would be needed to provide a network for Television Centre. But this network could not give complete all-to-all routing.

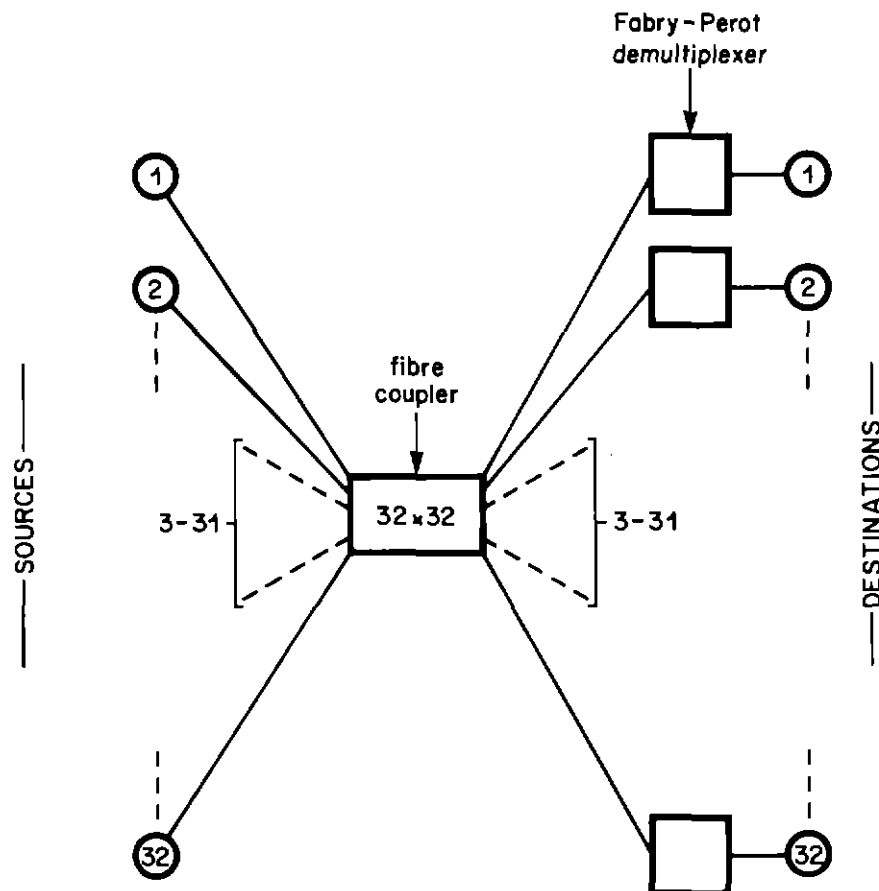


Fig. 21 - WDM with single-mode fibre.

Considerations of optical power would limit the size of the network to 32 sources and 32 destinations. The optical coupler could be fabricated by combining eighty 2×2 couplers such that each optical signal path only goes through five of them. Consequently, the loss through the coupler of any signal path is only 20 dB. This is made up of 15 dB division loss, 3 dB wavelength dependence and the remainder due to splice and scattering loss.

To achieve the requisite narrow channel spacing, DFB or external-cavity lasers would be used. The DFB laser is more suitable for operational use because of its small size, integrated construction and stability. There could however be a problem obtaining lasers at appropriate wavelengths, whereas a single design of external-cavity laser could be used for all 32 wavelengths.

9.8 Single-mode optical transmission with time-division multiplexing

The bandwidth of single-mode fibre is considerably higher than that needed to convey a digital video signal. Time-division multiplexing exploits this bandwidth, the limit being set by the optical interfaces and supporting electronics. At present bit rates up to about 2 Gbit/s are possible using commercial components.

A system capable of carrying 136 digital video channels could be provided, based on eight-channel multiplexing and 1×16 passive fibre splitters, as shown in Fig. 22. Seventeen local routing centres (LRCs) would be located at key points within Television Centre. Eight digital video sources would be connected to each LRC either electrically or optically. It should be possible to position each LRC

so that the distance to any of its sources is only a few tens of metres. The eight video signals are multiplexed into a single 2 Gbit/s bit-stream, and this modulates the laser transmitter directly.

A single-mode fibre from the LRC takes the multiplexed signal to a sixteen-way fibre splitter, the outputs of which are connected to all other LRCs. Thus there can be a total of 17 LRCs and 17 splitters.

The splitters can be in different locations. At each LRC sixteen optical receivers and associated electronics would detect and demultiplex the signals for transmission onwards to their destinations. Any number of destinations can be connected to an LRC, and fed independently.

Not all the LRCs have to be installed at once. As the various areas are converted to digital operation,

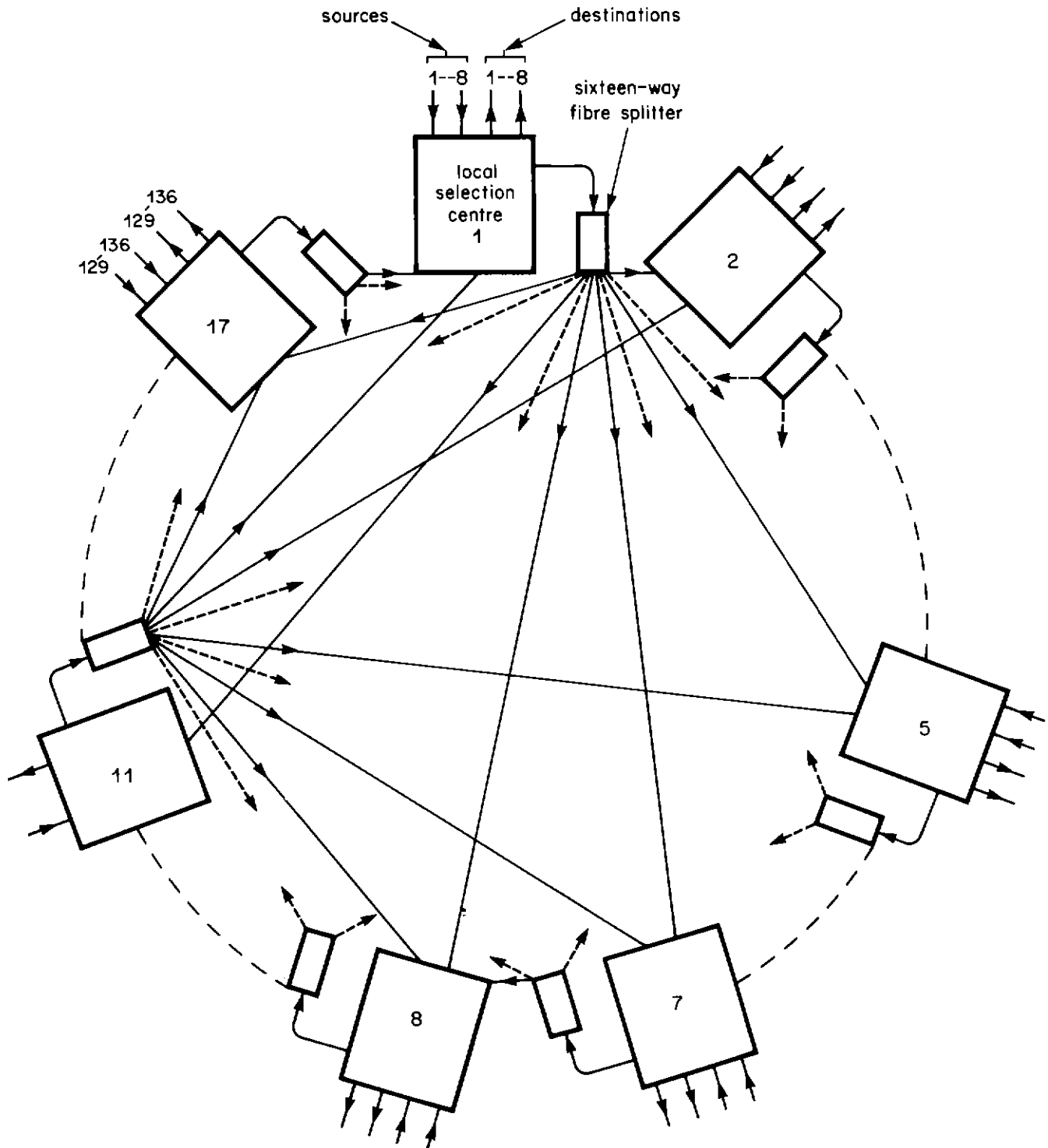


Fig. 22 - A 136-channel TDM system with single-mode fibre.

new LRCs are added as needed. Provided all the fibre splitters are installed initially, no further adjustments need be made to compensate for changes in optical power levels.

With regard to expanding the network, there would be enough power margin to split the signals about 30 ways. Thus the network could be doubled with 32-way fibre splitters. This would allow 33 LRCs, giving a capacity of 264 digital video signals. However, a better way of expanding the network is to use wavelength-division multiplexing, and this is discussed in more detail in Section 10.

9.9 Coherent optical transmission

As explained in Section 7.3, coherent optical detection can potentially increase receiver sensitivity by up to 20 dB and reduce channel spacing in WDM to within an order of the Nyquist limit for modulated signals. In a passive star network there is in theory enough sensitivity to divide the signal among at least 100 destinations, with each destination receiving at least 100 sources. Much research is under way to develop such systems, but they are not ready yet for practical use. Major problems are to be found with the production of a very narrow optical spectrum from semiconductor laser diodes, and with locking the phase or frequency of the local oscillator to the transmitter.

In the longer term coherent detection could be a means of increasing the capacity of a network based on WDM, without incurring the cost of replacing the original cables. New sources and destinations could be added by enlarging the splitter and adding extra cables.

10. THE PREFERRED SYSTEM: A WDM AND TDM HYBRID

In the near future neither TDM nor WDM alone can provide sufficient channels on a single bearer for a large studio centre. It was suggested in Section 9.8 that TDM and WDM could be combined to provide a much larger number of channels within the same power margin. This principle can be shown to be very flexible, in that the number of WDM and TDM channels can be varied to suit the application. The combined wavelength-and-time-division multiplexing (WTDM) system can be expanded in a number of ways, and ancillary signals can be readily incorporated. Very little fibre is needed for such a system in comparison with the amount of coaxial cable in the existing installation. This would limit installation costs and avoid overcrowding in the cable ducts during a changeover period.

The basic principle of such systems was proven in a WDM system reported by Olssen et al⁵⁵, which had the capacity to transmit 22 channels, each modulated at 2 Gbit/s. Such a system could in theory carry up to 176 digital *YUV* video channels. However the system described by Olssen was designed as a point-to-point link, and would need some rearrangement to be used as a distribution system.

The basis of the proposed system is shown in Fig. 23. The topology is that of the passive star, but variations and extensions are possible, and these will be discussed in Section 10.3. The basic system shown would route signals between 128 sources and 128 destinations. The sources and destinations are connected in groups of eight to each local routing centre, similar to those proposed in Section 9.8 for a TDM system. There are sixteen local routing centres, positioned throughout the studio centre, close to the sources and destinations that they serve. The connections between the local routing centres and their sources and destinations can be electrical or optical, according to distance and the need for electrical isolation.

Within the local routing centre the eight source signals are time-division multiplexed to form a serial bit stream at about 2 Gbit/s. The sound and ancillary signals could be added to the multiplex at this stage. The bit-stream intensity-modulates a laser diode which has a wavelength unique to that local routing centre.

The sixteen local routing centres are linked by single-mode optical fibre to a central 16×16 star coupler. The star coupler acts as a wavelength multiplexer and as a power splitter, as in the WDM system described in Section 9.7. The outputs of the star coupler are transmitted back to the local routing centres through a second set of fibres, and the sources are selected by wavelength-demultiplexing followed by time-demultiplexing.

10.1 The electrical section of the local routing centre

The electrical part of the local routing centre consists of sending and receiving sections as shown in Fig. 24. The sender multiplexes signals from eight sources into a single digital signal to modulate the laser.

The receiver is more complex. The sources are selected in two stages. First, a small matrix selects the appropriate 2 Gbit/s signal from the detectors. This matrix must be able to transmit 2 Gbit/s signals, although the switching action itself can be slower. The source itself is then selected by demultiplexing the 2 Gbit/s signal.

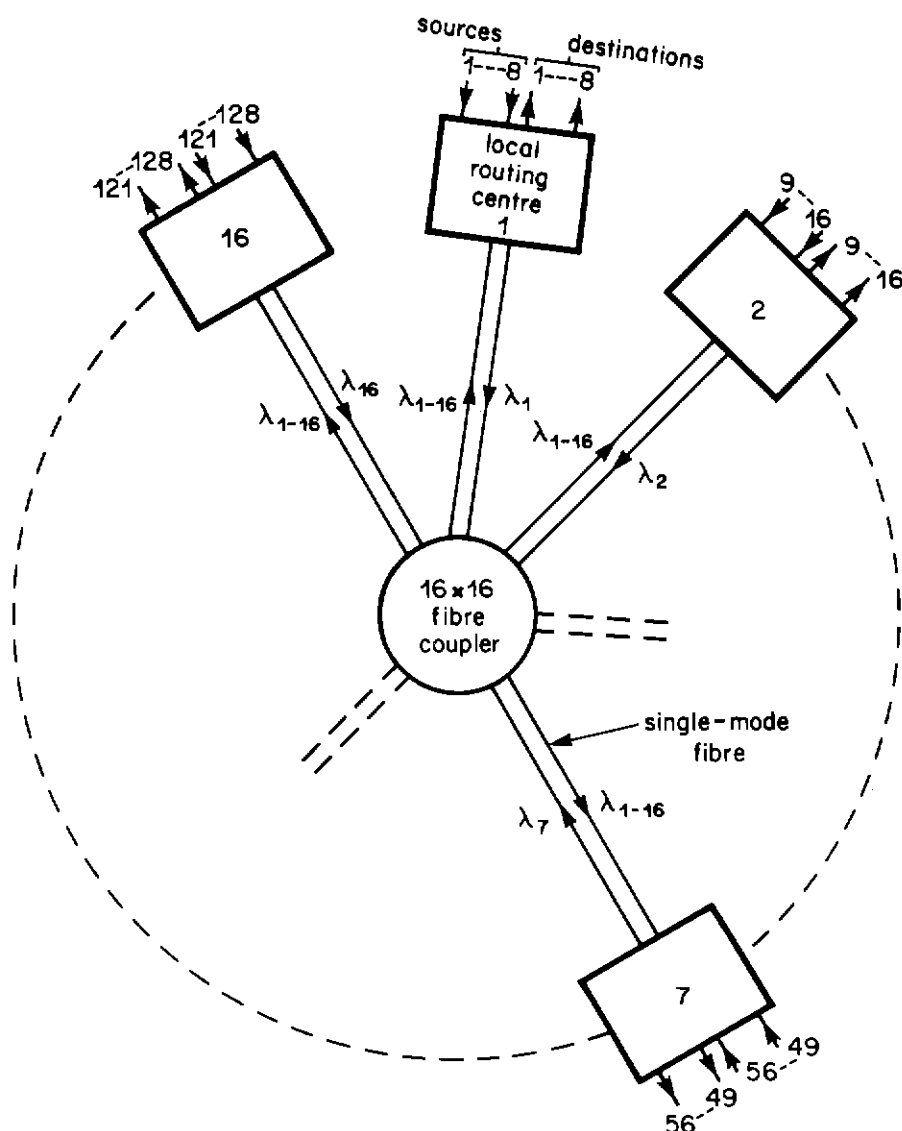


Fig. 23
A 128-channel combined TDM
and WDM system.

The difficulty of the electrical system lies in the circuits operating at 2 Gbit/s. Large-scale integrated circuits on silicon could be used for the high-speed electronics⁵⁶, but may not be economic unless many systems are to be made. For small-scale production, the circuits could be assembled from the families of GaAs logic that are becoming available⁵⁷. The local routing centres will be more complicated than is shown in the figures because of the need to incorporate sound and ancillary signals, and to provide control signals.

10.2 The optical section of the local routing centre

The optical system is similar to that described in Section 9.7. The principal difference is that a diffraction grating must be used for the demultiplexer because simultaneous access is needed to all wavelengths.

The choice of operating wavelengths depends

on the resolution of the optical demultiplexer, the wavelength dependence of the fibre coupler and the range of laser wavelengths available. In the system described by Olssen et al⁵⁵ the wavelengths were spaced 1.35 nm apart, equivalent to about 170 GHz separation at 1550 nm.

The demultiplexer would be compact enough to fit behind a 4-unit high panel. Because of the small channel spacing the optical components should be assembled on a rigid frame made of materials with a low thermal expansion, and possibly enclosed in an oven. Development should be aimed at eliminating any adjustment from the demultiplexer, which would also cause drift. Any slight adjustments will have to be made by tuning the optical sources.

Optical detectors for 2 Gbit/s operation are just becoming commercially available although they are presently very expensive. Only 15 detectors are actually essential, since a local routing centre does not have to detect its own output. However, this would

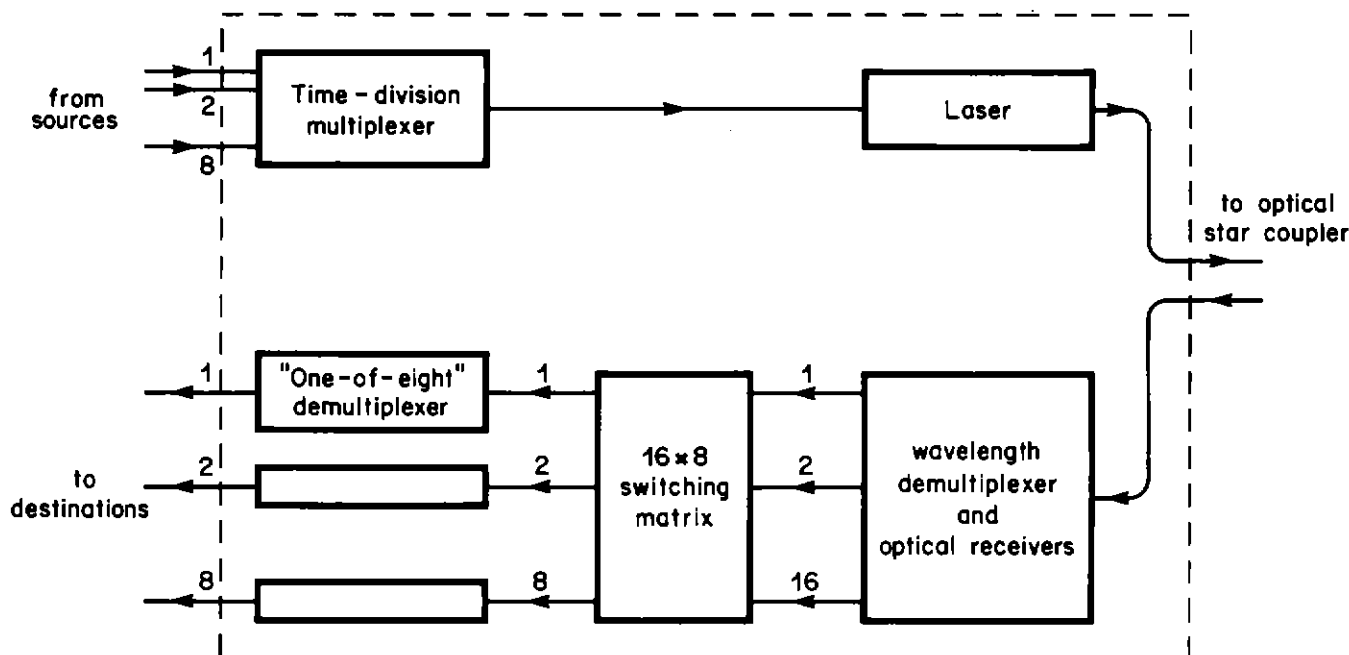


Fig. 24 - A local selection centre.

provide a useful method of monitoring and controlling the system, allowing, for example, active control of laser wavelength. The detector in the home channel could be a slower, hence cheaper device.

Table 2 shows a power budget for the proposed system, based on conservative estimates for each element. The power margin is 5.0 dB, which is acceptable. The estimated insertion loss for the demultiplexer is taken from Olssen et al. A figure of 5 dB is allowed for demountable optical connectors. Permanent fusion splices may now be preferable. They

are less lossy, more reliable, and with modern fusion-splicing equipment are easy to apply.

10.3 Extending the network

Variations of the basic arrangement can be devised, to circumvent the limitations of optical power and permit larger systems to be assembled.

One configuration, shown in Fig. 25, uses a second optical network in parallel with the first to double the size of the network. Any number of TDM/WDM systems could be stacked in this way to provide a larger routing system. A sixteen-layer system would be broadly equivalent to the TDM system described in Section 9.8 with WDM expansion.

This technique could also be used with a lower level of WDM to provide the original number of channels, but with a simplified demultiplexer. Problems of obtaining sources at suitable wavelengths would be less likely to arise because the number of optical channels would be less.

TDM/WDM systems could also be connected in series as shown in Fig. 26. In this configuration a pair of local routing centres, one from each system, is connected back-to-back to act as an interface. In this way an existing system could be extended, or separate systems interconnected, provided the restricted number of routes between the two systems was acceptable. Wider interfaces could be created by using more LRCs, but this reduces the number remaining to connect to sources and destinations.

Table 2
Expected power budget for an optical WDM system

Launched power	-1.5 dBm
Minimum received power	-31.0 dBm
Allowable loss	29.5 dB
Fibre loss (1 km)	0.5 dB
Coupler excess loss	2.0 dB
Coupler division loss (16 way)	12.0 dB
Coupler variation (5%)	0.9 dB
Crosstalk penalty	0.3 dB
Demultiplexer insertion loss	3.0 dB
Connectors (4 @ 1.25 dB)	5.0 dB
Splices (4 @ 0.2 dB)	0.8 dB
Total	24.5 dB
System margin	5.0 dB

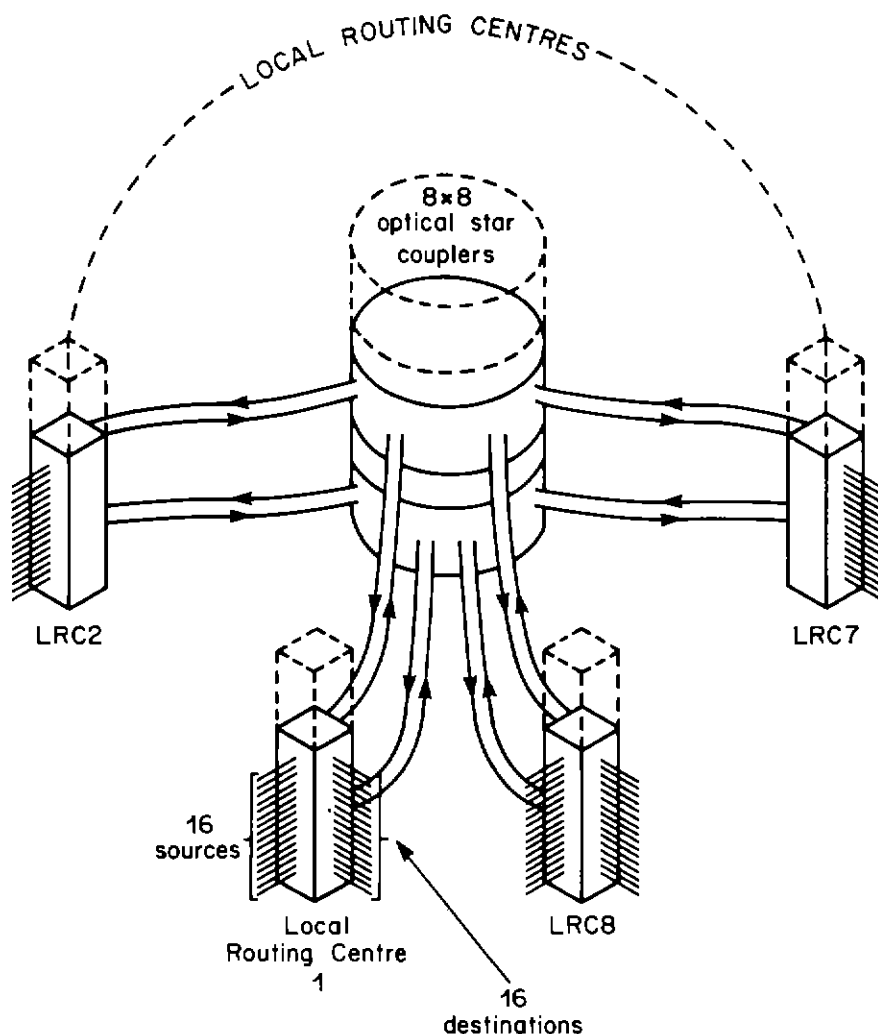


Fig. 25 - Combining systems in parallel to extend capacity.

10.4 The advantages and disadvantages of a hybrid TDM/WDM system

The proposed system has a number of advantages. These are:

- (i) Availability of all sources at all destinations.
- (ii) Sources are physically selected at their destinations, making control at the destination easy to provide.
- (iii) Flexibility; several different configurations are possible, and the system can easily be extended to provide more channels.
- (iv) Optical fibre distribution; no coaxial cable equalisation required and no electrical connection between areas to cause hum problems.
- (v) Electronic routing; no moving parts.
- (vi) Compatibility with the EBU/SMPTE remote control interface specification, which is also based on interconnected local centres.
- (vii) Accommodation of HDTV signals by using several 243 Mbit/s channels in parallel.
- (viii) Easy piecemeal installation during gradual conversion to digital operation; local routing centres can be installed as areas are converted.
- (ix) The proposed optical components have been proven to be practical.
- (x) The local routing centres are in fixed locations, so that the optical and 2 Gbit/s electrical equipment can be well protected, and environmentally isolated for good stability.

The main disadvantages are those commonly associated with new technology:

- (i) The need for special equipment and training for staff, particularly in maintaining the optical part of the system.
- (ii) The initial high cost of the optical and the high-speed electronic components, due to high developmental costs.

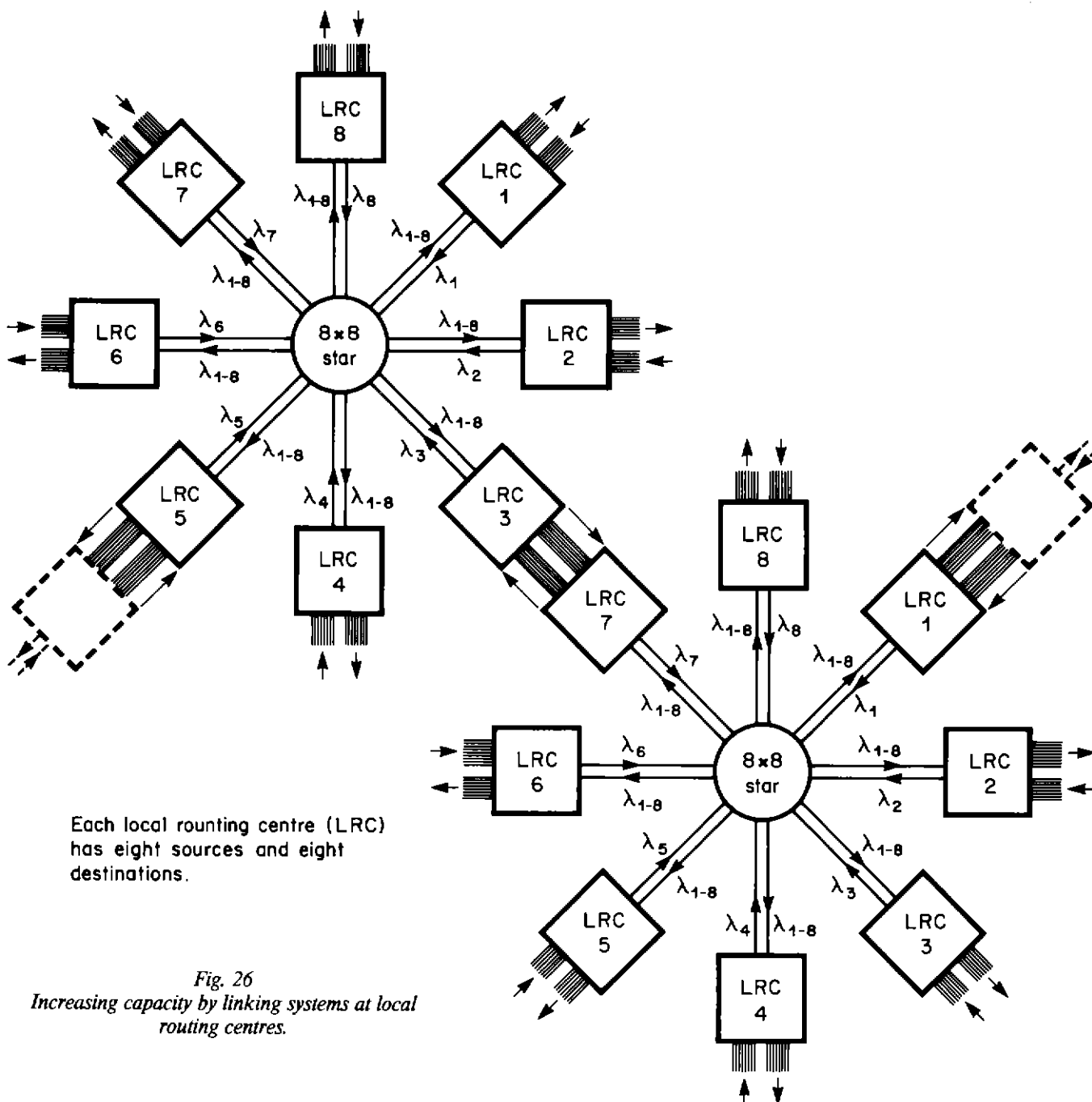


Fig. 26
Increasing capacity by linking systems at local routing centres.

11. DISCUSSION AND RECOMMENDATIONS

Conceptually the simplest type of digital video distribution system would be a switched-star network carrying electrical signals in parallel form. The problems are fairly simple to state, but not necessarily trivial to solve, for example, connector reliability and switch matrix design. Equipment could be connected directly to the network, but the profusion of cables and connectors would be a severe problem.

A system based on serial transmission would be more compact, because the number of signals would be an order of magnitude smaller. This would

be offset by the extra cost of the serial interfaces, although it is expected that special integrated circuits will be produced. Good radio-frequency practices would be needed in design, to minimise crosstalk, high-frequency loss and radiated interference. The system would need equalisers and regenerators requiring space, power and maintenance. Such a system would not reduce the large number of coaxial cables in the existing installation.

Replacing the coaxial cable with optical fibre on the longer interconnections would avoid high-frequency transmission problems. Using optical fibre throughout would be expensive mainly because of the

large number of electro-optic interfaces needed. The number of interfaces could be halved by switching the optical signals, but it is unlikely that an optical switching matrix of sufficient size will be developed in time for the proposed installation, if at all. A major problem is the lack of an optical amplifier to compensate the loss in a matrix. In the longer term, a semiconductor integrated optical switch array would be the most promising technique, because it could incorporate its own regenerators.

All of these systems would be difficult or impractical to extend to take high-definition television signals.

Optical systems using either TDM or WDM would make some reduction in the number of cables, but neither would provide the large number of channels needed. A better solution would be to use a combination of both techniques. Such a system would make all sources available at all destinations, simplifying source selection, and replacing the large central switching matrix with a simple optical coupler. Optical fibre and electronics would each be used to their best advantage, the fibre for transmitting wide-band signals without regeneration, the electronics for switching and signal selection. The system could be adapted to carry high-definition signals with changes only in the terminal devices, because the central element is a passive device of potentially very high bandwidth.

Installation of a system based on WDM and TDM could be carried out on a piecemeal basis. For the first digital studio only one LRC would need to be installed with all connections being electrical. On installation of the second LRC a point-to-point optical fibre link could be used. It would only be when subsequent LRCs were installed that the passive star and WDM system would be needed. This would spread the installation cost over a number of years and ease the changeover to the new system. The WTDM systems are sufficiently flexible so that changes needed as a result of operational experience can be easily made.

The routing and distribution system for a studio centre is a specialised application, and it might be thought that suitable components may be difficult to obtain. However, this is not thought to be the case. The high-speed lasers and receivers are already being developed for telecommunication links (there are discussions on standards up to 2.4 Gbit/s). Gallium arsenide integrated circuits are beginning to become available. The optical fibre and the couplers can already be bought. WDM itself is being widely studied for applications such as local area networks, and these are generally based on a passive star network⁵⁸.

Early fibre-optic components, in particular the lasers, gained a reputation for unreliability. However these problems have been overcome, to the extent that the next transatlantic telephone cable (TAT-8) will use optical fibres. It should be noted the optical part of the proposed system is not disturbed by day-to-day operational changes, which should ensure its reliability.

It is therefore recommended that the distribution and routing system be based on optical fibre transmission, using a combination of WDM and TDM; the WTDM system. A basic system can provide routing between 128 sources and 128 destinations. Further channels can be provided by adding further systems in series and in parallel.

12. CONCLUSIONS

The options for routing and switching of digital video signals have been reviewed. Electrical and optical techniques, and combinations of these methods have been discussed. Optical systems are better able to carry the high bit rate of the digital video signal, but have the disadvantages that there is no suitable optical switch or amplifier. However, these drawbacks may be avoided, by basing a system on multiplexing.

A hybrid time-division and wavelength-division multiplexed digital video routing system has been recommended. Its advantages are such that there would be no need to incorporate optical switching even if this were to become practical on a large scale. The system is easy to use, simple to install and offers operational savings. Other advantages include simple expansion to more channels, capacity for high-definition television operation, and the incorporation of sound and ancillary signals hence saving the cost of a separate ancillary network.

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